RETHINKING SCIENCE EDUCATION

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RETHINKING SCIENCE EDUCATION

The Fifty-ninth Yearbook of the National Society for the Study of Education

PART I

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Edited by

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Editor's Preface

The suggestion that the Board of Directors of the Society consider the possible desirability of publishing a new yearbook on the subject of science education was presented to the Board by a committee of the National Science Teachers Association in May, 1957. At the request of the Board of Directors, the general purposes and plan of the science yearbook were formulated in detail by the Association's committee, of which Professor Barnard is the chairman. The report of the committee was reviewed by the Board of Directors at its regular meeting in October, at which time the proposal was approved and the committee was directed to proceed with the preparation of the yearbook, selecting additional contributors to the yearbook as required. Mr. Havighurst was requested to serve as a member of the yearbook committee, representing the Board of Directors.

The Society's series of yearbooks has presented three earlier volumes designed to provide new emphases or directives to current practices in science-teaching. The first of these publications, Part II of the Third Yearbook, entitled *Nature Study*, was published with the view of establishing a functional relationship between elementary instruction in science and the natural sciences in the secondary schools. Part I of the Thirty-first Yearbook developed *A Program for Teaching Science*, which was directed toward the attainment of an understanding of the major generalizations of science and the associated scientific attitudes. Part I of the Forty-sixth Yearbook, *Science Education in American Schools*, urged further recognition of fundamental values in the advancement of scientific knowledge as well as in the improvement of science education.

Rethinking Science Education will be recognized as the painstaking endeavor of dedicated scientists to forecast the oncoming objectives of science education. As was to be expected, the various pronouncements of the text of this volume afford dependable guidance in the interpretation of significant trends in science instruction at present stages of progress in the development of new knowledge in the various fields of science. Thus, the pronouncement that "there are two major

aspects of science education; one is knowledge, the other is enterprise" (p. 34). And the cultural significance of these simple facts is epitomized in the discerning appeal of the following paragraph.

"Through the practical applications of scientific discovery our civilization is undergoing constant change. In turn, these changes bring about situations which threaten the well-being of future generations. The welfare of our civilization is now almost wholly dependent upon scientific progress. Society must respond with adequate and intelligent control" (p. 17).

NELSON B. HENRY

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CHAPTER I

The Role of Science in Our Culture

Introduction

J. DARRELL BARNARD

That science has played a significant role in the development of our culture is an obvious fact; that it will play an increasingly important role in our future development is, in light of present progress, taken for granted. What the exact nature of that role will be is a question with which all educators need to be concerned. Educational programs in schools and colleges must be appropriately conceived of and skilfully planned. Accordingly, this first chapter of the yearbook is given over to a consideration of the significance of science in our culture.

Three writers have contributed essays on different aspects of the general topic of this chapter. The first of these essays, entitled "Science and the Humanities," deals with the purposes and methods of science as contrasted with those of other disciplines through which man attempts to develop a better understanding of himself and the world in which he lives. The social impact of two highly significant technological advances, control of disease and control of energy, are examined in a second essay, "The Interaction between Science and Society." These advances are considerd not only in terms of their effect upon the present state of man's well-being but also in terms of the benefits and the hazards of new problems which they are creating.

Since 1945, the scientist has sought opportunity to discuss openly the role of science in our culture. He has expressed his views both as an individual and through the societies with which he is affiliated. In 1957, an Interim Committee of the American Association for the Advancement of Science presented a preliminary report on the "Social Aspects of Science."[1] This report made quite clear that scientists will no longer stand by with "closed eyes and a dumb mouth."

1. "Social Aspects of Science" (Preliminary report of the AAAS Interim Committee), *Science*, CXXV (January 25, 1957), 143-47.

In co-operation with other responsible citizens, they intend to take action upon vital issues.

As one evidence of its intention to act, the American Association for the Advancement of Science held its first Parliament of Science in March, 1958. A report of this venture is described in the third essay presented in this chapter, "Society, Education, and Science."

Through these three essays, science in our culture is examined, first, as a creative, intellectual activity leading to unifying concepts of man's natural environment; secondly, as the application of these concepts to the control of the environment for man's benefit; and, finally, as an enterprise which requires man's best efforts to sustain it at an optimum level of productivity.

Science and the Humanities

MORRIS H. SHAMOS

The launching of the first Soviet Sputnik was a forceful reminder that man has not yet succeeded in defining the common ground between his two great areas of knowledge, science and the humanities, for the resultant clamor for improved science education in the United States and greater support for science, generally, touched off an immediate and typical reaction from those whose interests lie chiefly, perhaps even solely, in the humanities. They argued, not that humanistic studies are more important to mankind, but that they should not be ignored in the rush for international supremacy in science. They were right, of course, but it almost appeared as though battle lines were being drawn once again, with the humanities on one side and science forced to the other.

This is an old controversy that dates back roughly to the beginning of the modern period in science. It seems that, from the time science first exerted a noticeable influence on the affairs of men, it clashed with the traditional forms of liberal culture. There can be little doubt that the conflict stems more from a misunderstanding of the nature of science than from some basic incompatibility between scientific and humanistic pursuits.

Modern science is only some three centuries old; yet, in this relatively short time it has made a deep and lasting impression on modern civilization. Virtually no segment of human activity has been left untouched by the results of scientific thought. Whether science

has always worked for the over-all good is to some humanists (and scientists) a matter for debate. But it is idle to speculate on this point, for we are unable to turn back the clock. For centuries philosophy was conceived of as embracing all knowledge worthy of interest for its own sake, but the rapid development of science forced its separation from philosophy, a process not completed until the nineteenth century. The conflict between science and the humanities can be traced largely to the importance accorded by science to its experimental aspects as distinguished from its purely speculative nature and to technology, which inevitably grows with a science and which provides it with stimulus for further development.

When Plato discussed how best to educate the future leaders of society, he took the position that, to arrive at an idea of "the good," one must study, among other things, the hypotheses and basic concepts of the natural sciences.[2] Unfortunately, this conception of science was quite different from the modern view. He scorned experiment, thinking that the only true knowledge was that derived from pure philosophical speculation. It was inconceivable to him that, to understand nature, one had to enlist its aid. This would have been totally inconsistent with the teleological scheme of things. After all, was not nature "designed" for the good of mankind? To understand it, therefore, one simply had to seek the ends or purposes which it served, giving free rein to the imagination. This mode of explanation not only appealed to the early Greeks, at least to the followers of Socrates, Plato, and Aristotle, but also set the pattern for centuries of hopeless confusion in science, a pattern finally broken by the intellectual strength of the Renaissance. As science leaned more and more on experiment to add to man's understanding of nature and sought explanations in terms of initial causes of things rather than the ends or "goods" they served, it prospered. Yet it appears that the very factors which led to the exploration of the phenomena of science became the chief source of contention in this strange controversy.

Science came under sporadic attack from those humanists who questioned the intellectual value of a study which they regarded as mechanistic and routine. And as the methods and techniques of scientific investigation grew more precise, these humanists were

2. Plato, *The Republic*. Translated by R. Jowett. New York: Modern Library, 1941.

strengthened in their conviction that creative imagination and appreciation of beauty played little, if any, role in the scientific study of nature. With the industrial revolution a new factor was added, namely, the utility of science. Perhaps more than any other aspect of this enterprise, its utility has conveyed a false impression of the nature of science, particularly in modern times.

The famous French mathematician and philosopher, Henri Poincaré correctly described the true motives of science: "The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful."[3]

The layman, unfortunately, finds it difficult to reconcile this view with the outward impressions he gets of science. He finds himself surrounded by the material products of science. His habits, his mode of living, his health, perhaps even his freedom to enjoy the arts—all are conditioned by advances in technology. He is aware, furthermore, that such advances generally result from specific needs of society rather than the creative spirit of man. Can he be convinced that there is far more to science than the end products that meet his eye or that men do not engage in this pursuit solely to fashion such things as automobiles, radios, and electric lights? Not readily!

The average man, as well as the humanist, has held such a partial view of science. He confuses pure science with applied science or technology. The two strengthen one another but differ greatly in basic values. Not that technology has less value, but it is a kind of value remote from the ken of the humanist and is not what is meant by science. That some humanists hold a totally irrational view of science is clear from the nature of their arguments. They lament the changing scene; they deplore the inroads of technology on nature; they fear that the literary and artistic classics of the past may be lost from view because they will no longer evoke meaningful memories. They regard the whole of science somewhat in the same light as its military potential: a barbaric enterprise destined to halt the cultural development of civilization. No doubt most individuals, scientists included, who have witnessed some of the changes brought on by modern technology, look back with a certain nostalgia to the "simpler life" of earlier times. But the changes mark the direction that

3. H. Poincaré, *The Value of Science*, p. 8. Translated by George Bruce Halsted. New York: Science Press, 1907.

civilization has taken, and the poet, rather than cling solely to the cultural riches of the past, must record that which is significant on the contemporary scene.

Perhaps the greatest injustice that can be done to science is to regard it merely as a collection of facts, and the practice of science as little more than the routine accumulation of minutiae. It is true that science deals with hard, inflexible facts, but it has also to do with very general ideas and abstract principles; and it is the co-ordination of these ideas and observed facts that is the essence of modern science. Facts alone do not constitute a science. *Nature study* is not the same as the *study of nature*.

What, then, is science? It is the search for *order in nature*. The scientist seeks to account for nature in the simplest possible terms; that is, with the greatest economy of thought and expression. This is, after all, what is meant by *explanation* in science. The humanist seeks a similar economy of expression but in a somewhat different sense. The poet, Coleridge, defined beauty as *unity in variety*, and described the arts, poetry, painting, music as the search for this unity. The creative artist seeks to encompass in a single poem, in a painting, in a musical composition, a certain segment of human experience. In much the same way the scientist seeks for unity amid the great variety of nature. Both study nature because it is beautiful, but they regard beauty in different ways. After describing what motivates the scientist to study nature, Poincaré went on to distinguish these kinds of beauty:

> Of course I do not here speak of that beauty which strikes the senses, the beauty of qualities and appearances; not that I undervalue such beauty, far from it, but it has nothing to do with science; I mean that profounder beauty which comes from the harmonious order of parts and which a pure intelligence can grasp.[4]

Were it not that nature works in essentially simple fashion, there could be no science. Suppose, instead of having roughly one hundred different chemical elements in nature, we had one hundred billion, all uniformly distributed. Then as Poincaré pointed out,[5] the chance of finding two objects in nature bearing some resemblance would be extremely remote. Whatever we might know of parts of

4. Poincaré, *op. cit.*, p. 8.

5. *Ibid.*, p. 5.

nature would avail us little in our efforts to understand the whole. All things would be different. Science could be no more than an interminable accumulation of isolated facts.

Nor could there be any art. Nature would defy description by the humanist as well as the scientist. Neither one could evoke memories of the past nor provide useful ideas for the future. Imagine man's range of hearing or the spectral limits of his vision to be multiplied a thousandfold, and think what effect this would have on music and the visual arts. That order and simplicity are prerequisite to all forms of knowledge must be evident.

On the other hand, it should be clear that there are significant differences between the sciences and the humanities. The latter are concerned with man himself, with his whole being and his interactions with the world about him; the sciences are more objective, less concerned with the ways of man than with his understanding of the ways of nature. There are no simple definitions of these disciplines. A work of art is a finished thing; it need not build upon the past nor form a foundation for the future. It is complete and unique in itself. Science, however, is tentative and accumulative. Its structure has been built up over the ages, but always of removable bricks, so that the weaker ones, when discovered, may be replaced by stronger. It is the cumulative nature of science, according to Conant,[6] that distinguishes it most from other forms of intellectual activity. He points out that while progress is expected in the sciences, it is not a characteristic of the humanities. The criterion actually goes much deeper. One may question, for instance, whether it is meaningful to speak of progress in connection with the humanities. A more useful, though perhaps related distinction would seem to be the matter of self-consistency. Science has evolved means of testing the truth of its statements about nature. These methods, while not infallible, have on the whole proved successful in guiding science along the correct path to knowledge. The humanities, however, despite frequent claims to *self-evident truths,* have no logical rules for testing its accomplishments. Indeed, the concepts of truth and falsity cannot even be applied to humanistic knowledge, for it is meaningless to ask whether a work of art or a poem can be justified on this ground.

6. James Bryant Conant, *Science and Common Sense.* New Haven, Connecticut: Yale University Press, 1951.

Regardless of these differences, there appear to be no valid reasons for mutual antagonism. Both scientist and humanist, as we have seen, are motivated by a common goal, the search for order. They seek this goal in different ways; but each, to claim achievement, must display creative imagination. The basic difficulty is a lack of mutual understanding. One kind of knowledge cannot replace the other. The major problems of modern civilization will not be solved by science alone but by a combination of science and human wisdom. Each one, scientist and humanist, has the responsibility of seeking the common ground.

The Interaction between Science and Society

L. V. BERKNER

The dependence of society on ideas and devices that emerge as a consequence of scientific research has increased greatly since the origins of modern science in its golden age, the sixteenth and seventeenth centuries. The great scientific figures of that age were motivated solely by the burning curiosity to comprehend and to describe the behavior of nature. But the brilliant contributions to scientific knowledge since their time have been reflected to an ever increasing degree in dependent changes emerging from our civilized activity. Almost every present activity of man rests on the fruits of science. Therefore, the scientist is no longer motivated solely by curiosity concerning nature, for the practical applications of scientific enterprise cannot be ignored. Moreover, the motivation of civilization in supporting science is strongly influenced by the expectation of new benefits that science can provide. As a result, the interaction between science and society is continuously strengthened. Indeed, the welfare of society is now principally founded on an optimum of scientific progress.

The extent of society's dependence on science is easily forgotten, and we might well be reminded of just a few important changes that science has wrought in our environment. Consider the impact of medical research. In the past two centuries, men of medicine have raised life expectancy of human beings from their late twenties to their sixties. Moreover, infant mortality has declined to such an extent that six babies are saved of each seven that would have died at the time of the American Revolution. The average man can now

live a normal life with reasonable expectancy of remaining well without facing the threats of disease and disability that have haunted past generations. In fact, physical health has advanced in such mighty strides in the past century that the whole fabric of social organization has been reconstructed around social attitudes that recognize the dignity of man in an atmosphere almost free of epidemic disease and disabling organic malfunction.

The triumphs of present-day medicine are easy to overlook in our era when bad health is the exception. We should not forget the shocking conditions of human life extending backward through history and up to the last century. Concerning these, Hans Zinsser wrote as follows:

> To the miseries of constant war, political and social disintegration, there was added the dreadful affliction of inescapable, mysterious, and deadly disease. Mankind stood helpless as though trapped in a world of terror and peril against which there was no defense.[7]

The scourge of disease has continued unrelentingly to combat man's hopes for civilization and humanity until very recent times.

As world populations grew slowly through history to a few tens of millions, man followed his social instinct to congregate into groups and cities where he could create and enjoy the intellectual values that a civilized social order can afford. He built roads and improved communications whereby he could benefit from social progress beyond his city. But without the benefits of science applied through effective medical ministration, these efforts toward civilization became ever more exposed to the mysterious visitations of pestilence that seemed

> . . . expressions of wrath of higher powers which came out of a dark nowhere, pitiless, dreadful, and inescapable. In their terror and ignorance, men did the very things which increased death rates and aggravated calamity. They fled from towns and villages, but death mysteriously traveled along with them. Panic spread social and moral disorganization; farms were abandoned, and there was a shortage of food; famine led to displacement of populations, to revolution, to civil war, and, in some instances, to fanatical religious movements which contributed to profound spiritual and political transformations."[8]

7. Hans Zinsser, *Rats, Life, and History*, p. 80. New York: Blue Ribbon Books, circa 1934, 1935.

8. *Ibid.*, p. 129.

Three centuries ago, the climb of civilization had almost come to a halt until science, and its application in medicine, could bring disease and pestilence under control.

Can any of us yearn for "the good old days" before scientific research could provide, at least in some measure, the means and the tools to deliver us from these terrors? For, until relatively recent years, man's history has been an era of wretchedness and incredible brutality where the low value of human life, in the face of uncontrolled disease, provided little hope for individual freedom, dignity, and respect.

But in winning relief from epidemic and death, we find that each palliative provided by science introduces new and formidable problems. We live in a dynamic world where change is the rule. Nothing can long remain fixed. We see, for instance, the enormous change that has been induced by the conquest of disease. No one would say that this conquest has not been a good thing. Yet, in improving our lot, we produce at each step new problems that themselves are serious and must be solved. Moreover, change is often beyond our control, for Mother Earth herself is not static and the environment that she offers is constantly varying. Consequently, our civilization undergoes constant and rapid change. Adjustment to the dynamic change of civilization and its environment is the central challenge of the future.

Consider the problem of population growth that arises directly as a consequence of our success in controlling disease. With the recent increase of the life span from 25 to 65 years, an uncontrolled birth rate, and greatly reduced infant mortality, the world's population is increasing at an astonishing rate.

Think for a moment what this means. The world now has a population of 2.6 billions. Less than a century ago, it was about half of this. Projections of world population for the year 2000, based upon different assumptions of net annual increase, range up to approximately five billions.[9] We are presently adding each day the equivalent of a city of nearly one hundred thousand, with its further reproductive capacity. In countries like China, with its population of more than six hundred million and its life expectancy of thirty years,

9. L. Dudley Stamp, *Land for Tomorrow: The Underdeveloped World*, p. 30. Bloomington, Indiana: Indiana University Press, circa 1952.

we have yet to see the full effect of antibiotics and other modern medication and medical procedures.

Science can go far in multiplying supplies of food and resources. But certainly there is some limit in the geometric multiplication of the earth's population. Are we to allow this limit to be imposed by famine and disease, or can we find some more rational procedure for handling it? Our hope of the 1930's, that population would stabilize in a mature industrial economy, has been shattered by our own increasing population rate as prosperity has returned. In finding an answer to the population problems, scientific research will be at the forefront, for the problems of medical care, sanitation, and epidemiology will press science hard for solutions to the problems of population increase.

With these examples of the impact of medical research on society, let us turn to a quite different but major instance of influence of science on civilization. Consider, briefly, our world from the point of view of the energy that it provides us. It is hardly necessary to explain that energy is fundamental to man's existence. Aside from the energy needed for food and a minimum of warmth that is common to all biology, it is energy under man's control that forms the basis of his civilization. In his quest for better living and for time to follow intellectual pursuits, which are the bases of civilization, man first used slaves and animals as his principal energy-source. Then, man learned to use the wind to sail his ships and a little waterpower to grind his flour. But until two centuries ago, this was about the limit. The man without slaves or other sources of energy was poor indeed.

The industrial revolution and, with it, the revolution in our civilized habits, was started by James Watt, whose steam engine was to make controlled energy abundant. With the coming of simple electrical transmission of energy over great distances by fixed conductors, the first stage of the industrial revolution was complete. Each man, woman, and child in the United States now has the equivalent of more than two hundred slaves at his disposal. Energy has made each of us a king in contrast to the miserable situation of our forebears.

This change has not been a slow evolution. Rather, it has been a sudden revolution emergent from the growth of scientific thought,

Man's written history is but three hundred generations old. So close are we to the beginning of civilization that, with the present multiplication of populations, those who are now living constitute about 7 per cent of those born throughout history. Power in substantial quantities under man's control goes back only six or seven generations. Yet, we routinely accept the mechanical slaves that power gives us as though they had always been present. They are a part of the civilization that science has given us. But what problems does the provision of energy pose for the future?

At present, the United States uses about 1×10^{13} (ten thousand billion) killowatt hours of energy annually, including conversion loss. By conversion loss is meant the energy required to get the fuel and make it usable. If we expend a pound of coal to provide energy to obtain another pound of coal, the conversion loss is 100 per cent, and we are back where we started since we have gained no energy. Likewise, if we must have our energy in liquid form, such as gasoline or alcohol, there is an additional loss if it is converted from coal or grain. Clearly, in obtaining heat from fuel, we must come out with more heat than is required to mine and deliver it, or the fuel is useless as a source of energy. In the United States, our present conversion losses for coal are about 16 per cent, that is, an expenditure of one pound to obtain six. But we are now mining the coal and oil that is easy to get. In a hundred years, all the fuel that is easily accessible will be gone. In Great Britain, the conversion loss has already risen to 33 per cent. The most conservative estimate indicates that a century from now the conversion loss will be above 50 per cent, that is, one pound for two. How much farther can we go with this?

Because of increased useful demand and higher conversion loss, we can estimate that energy requirements of the United States in one hundred years will multiply by five or six, to perhaps 6×10^{13} kilowatt hours per year. A few curves and some simple calculations show that our useful fossil fuels will be pretty well exhausted in 150 to 175 years. Those who predict that coal will last a thousand years fail to appreciate the significance of conversion loss, where the billions of tons in thin seams may be useless as fuel.

This is so startling that we must look at it more closely. What about fuel supplies in the rest of the world? Unfortunately, the

fossil fuels are only found in the temperate zone. They have not accumulated near the equator because biology rots too quickly. Not enough biology has lived near the poles to leave great reserves. Therefore, such fuels are available in substantial quantity only over very limited land areas. For these and other geological and meteorological reasons, other areas of the world are generally less prolific in fossil fuel than the United States, so that their total cannot be much more than two or three times that of the United States. If, in the next fifty years, the people of the world develop the living standards they appear to be acquiring, they will use up the remaining stores faster than we, for our population is only 5 per cent of the whole.

In a philosophical sense, man was provided with easy access to a store of readily available energy, the fossil fuels, to develop his mechanical potentialities. But these resources are extremely limited and, in the expanding economy that they encourage, can last a total of only 10 or 15 generations. That is 3 to 5 per cent of the period of man's history. He is given this short interlude to use his newly developed mechanical skill to acquire new and more permanent sources of useful energy. This is a task that faces science and technology in its support of an ever higher civilization. Both the newly discovered forms of nuclear energy and the suitable conversion of solar energy, either organically or inorganically, offer great opportunity and challenge. Here science and society must interact favorably to maintain our social standards.

As in the fields of medicine, and of energy, so in every field of human endeavor one finds society critically dependent on science. But science can produce its solutions only if it can be nurtured in an atmosphere that provides opportunity and retains creativity. To realize the benefits that science must give to civilization to ensure its continued rise, society must, in turn, provide an adequate support to science that it may function effectively.

In a recent Condon Lecture, the great astronomer, Otto Struve, reminds us:

> In the second half of the 15th century the leading nation in the field of navigation and geographical exploration was Portugal. . . . But when Columbus applied to the King of Portugal for aid in organizing an expedition toward the west, across the Atlantic Ocean, he encountered only lack of interest and scepticism. The voyages of Columbus were financed

by Queen Isabella of Spain, and from this small investment sprang Spain's great colonial empire....

Until October 4 [1957] we felt secure in our belief that we were the leading nation in science and engineering. But on that date we suffered a humiliating defeat, and one that may go into history as of comparable significance to the defeat which Portugal experienced in 1492 when King John II of Portugal lacked vision and Queen Isabella of Spain possessed it.[10]

The interaction between science and society is real, for, to earn the benefits that science can provide, society must respond with adequate and intelligent support.

Society, Education, and Science

DAEL WOLFLE

Scientists and scholars have become increasingly interested in education. Hopefully, this may be one of the permanent gains from all the recent discussion, uncertainty, and controversy over the American school system. For some years there has been a growing gap between school teachers and administrators, on the one hand, and scholars and scientists, on the other. Yet these two groups must work together if the education provided by American schools is to be as excellent as both groups wish. Without the help of scholars and scientists, the schools cannot know what to teach. Without the help of teachers and administrators, the subject-matter courses cannot be taught at all at precollege levels.

Despite the interdependence of the two groups, there has been a gulf between them, with harmful consequences for the students. Schools have been cut off from the stimulating effect of close contact with research scholars who are advancing knowledge; some courses—most notably those in mathematics and science—have grown sadly out of date and no longer give the student an adequate picture of current thinking and problems; universities and colleges have frequently found it necessary to begin their instruction at a lower level than should be necessary; and superior students have frequently been forced to spend more years in acquiring a general education than should be necessary.

In all the recent discussion of educational problems, one conclusion that has stood out most strongly is the necessity of paying

10. Otto Struve, *The Astronomical Universe.* Condon Lectures, Oregon State System of Higher Education, Eugene, Oregon, 1958.

greater attention to quality and to the raising of intellectual standards. This emphasis has served to rekindle the interest of scientists and scholars in what goes on in elementary and secondary grades and has resulted in several potentially highly beneficial expressions of that interest.

One example was the Parliament of Science held by the American Association for the Advancement of Science in March, 1958. Interest in the improvement of education was one of the reasons for convening the Parliament of Science, but there were other reasons. Scientists have been growing increasingly aware of the fact that rapid scientific progress is producing more and more complex interrelationships between science and society and that both scientists and others must give thoughtful consideration to these interrelationships. Atomic fission and fusion, rapid advances in genetics and the control of disease, accelerating ability to explore beyond the earth's atmosphere, and, in general, growing understanding and control of the forces of nature make scientific knowledge and understanding an ever more necessary element in major industrial, governmental, and social decisions.

The Parliament of Science was a demonstration of the scientist's concern about his own role in helping society meet the problems thrust upon it by the accelerating pace of scientific advance. More than one hundred participants devoted three days of intensive discussion to five topics: the support of science; the organization and administration of science in government; communication among scientists and communication of scientific ideas; the selection, guidance, and assistance of students; and the improvement of teaching and education. Most of the participants were scientists, but the list also included representatives of education, politics, business, law, religion, labor, and mass media of communication.

On each of the five topics discussed, the participants reached agreement on a number of principles and recommendations.[11] Some of the agreements concerning the improvement of teaching and education provide a good indication of the considered judgment of a widely representative group of scientists toward current educational problems.

A pervading attitude toward the relationships between education

11. The full report of the 1958 Parliament of Science conducted under auspices of AAAS was published in *Science,* CXXVII (April 18, 1958), 852–58.

in science and education in other fields was expressed by the Parliament in this way:

> We believe that the primary goal of education should be the intellectual development of the individual. With its accelerating importance in our society, science has become an increasingly important part of general knowledge. We believe that scientific education is best fostered as a part of a general emphasis on intellectual activity and that the pressing need is for increased support of the social sciences and humanities as well as the natural sciences [p. 857].

The Parliament stated its judgment that "education in science, mathematics, and other subjects could be improved by generally raising university and college entrance requirements," and suggested that the raising of such standards be done in consultation with representatives of secondary schools so that there would be mutual understanding and an orderly process.

Because the Parliament was concerned with the place of science in general or liberal education, at least as much as in the education of scientists, attention was given to the kind of science course that would be of most general value.

> The teaching of science should give due emphasis to the nature of science itself. It should not be simply a collection of facts. It should show the way in which scientific conclusions are drawn by rational processes from observations and should emphasize the tentativeness of these conclusions. It should keep alive that curiosity and enthusiasm for learning which are so necessary for all intellectual pursuits [p. 857].

Because there is much to be learned about how science and other subjects can be taught most effectively, how learning can best be fostered, and how the primary intellectual objectives of education can best be integrated with the other objectives of the school system, the Parliament urged support for research designed to improve the methods of attaining the goals set forth in the preceding several paragraphs.

The awarding of scholarships to able undergraduates is a frequently suggested method of providing federal aid to education. Usually these recommendations concentrate on scholarships for students in science and engineering because of the relation of those groups to national defense. The attitude of the Parliament of Science was a firmly expressed statement that scholarship or fellowship awards should be made solely on the basis of merit and that a feder-

ally supported undergraduate scholarship program should place no restriction upon the choice of field selected by scholarship winners.

In an over-all review of its recommendations, the Parliament established the following order of priority for federal and other funds that might become available for the improvement of science education: "(i) improvement of education and encouragement of teachers by better salaries and opportunities for further learning; (ii) new construction, facilities and equipment; (iii) scholarships."

The necessity for joint work by all groups interested in the improvement of education was emphasized by the Parliament in urging "scientists and scientific organizations to take the initiative in co-operating with various state and local groups concerned with primary, secondary, and college teaching."

The 1958 Parliament of Science from which these few conclusions have been quoted is one illustration of the fact that scientists have again become seriously concerned with education at all levels and in its broader aspects. Science itself is advancing with such rapidity that unless scientists, humanists, teachers, and other elements of our complex society work co-operatively together, the difficulties which now beset American education cannot be solved. One passage from the Parliament report provides a fitting conclusion.

> What faces man is not, in any restricted sense, a scientific problem. The problem is one of the relation of science to public policy. Scientific issues are vitally and almost universally involved. The special knowledge of the scientist is necessary, to be sure; but that knowledge would be powerless or dangerous if it did not include all areas of science and if it were not effectively pooled with the contributions of humanists, statesmen, and philosophers and brought to the service of all segments of society.
>
> What is to be done? Scientists certainly have no arrogant illusion that they have the answers. But they do want to help. They are, moreover, convinced that the time is overripe for a more understanding collaboration between their special profession and the rest of society [p. 852].

Summary

J. DARRELL BARNARD

Although much of modern science is of comparatively recent origin, its "practical" aspects have had far-reaching impact upon our culture. Unfortunately, science is too frequently viewed *only* in this light. Its purely speculative nature, whereby the creative imagination of man seeks unity amid the great variety of nature, is not so

well understood. When viewed in this light, science becomes less antagonistic to the other ways by which man seeks order in his world. It is through science that man seeks to understand this order by self-correcting methods that put limiting values on his preconceptions.

Through the practical applications of scientific discovery our civilization is undergoing constant change. In turn, these changes bring about situations which threaten the well-being of future generations. The welfare of our civilization is now almost wholly dependent upon scientific progress. Society must respond with adequate and intelligent control.

There may have been a time when scientists preferred to let others assume the responsibility for our destinies as they relate to technological advances. Not so, today. Scientists are particularly concerned about the ways in which they can help solve problems which have been brought into sharper focus through scientific advancements within this generation. One such problem is the improvement of science-teaching in the schools.

In this yearbook the purposes of science education are reassessed in light of the increasing significance of science in our culture. The nature of the learning process as it relates to achievement in science is dealt with at some length. Procedures for planning and implementing science-teaching at each level from the elementary school through the junior college are explained. In recognition of the advanced training exacted of the science teacher, both his preservice education and his in-service professional developments are described.

A number of questions will go unanswered because the evidence which is needed for answers is not available. A chapter on needed research in science-teaching points up these gaps in our knowledge.

Colleges and universities have a number of responsibilities for the kind of science-teaching that goes on in the schools. They educate the teachers, supervisors, consultants, and administrators. They supply consultant services to schools. They are responsible for most of the research in science-teaching. The implications of what has been written in this yearbook for colleges and universities are treated in chapter xvii. The final chapter is devoted to the issues in science education as the committee has seen them emerge through its work in preparing this yearbook.

CHAPTER II

Science Education for Changing Times

Introduction

PAUL DeH. HURD

The march of science just preceding and following the mid-period of the twentieth century has caused educators to realize that science-teaching must differ in emphasis, purpose, and kind from that of the preatomic and premissile eras. During the past twenty years science has contributed many distinguishing characteristics of our civilization. National security, economic stability, public welfare, and the maintenance of a free society are intimately related to the discoveries of science and the applications thereof. The emerging scientific revolution, together with the trend toward world industrialization, demands a program of science education with new dimensions. More than a casual acquaintance with scientific enterprise is essential for effective citizenship. It is apparent that now is the time to evaluate and redefine the purposes of science-teaching.

THE NEED FOR CLEARLY DEFINED OBJECTIVES

An important process in the planning and development of a science curriculum is that of identifying its purposes. These become the objectives that orient the teacher's efforts and define the responsibilities of the learner. Objectives indicate the nature of the educational endeavor and denote the direction it should take; they serve as a guide for the choice of teaching procedures and provide hypotheses for making curriculum decisions. They suggest to the teacher why his work is important, how to plan it, and how to evaluate it. Only when objectives are clearly identified and supported by a personal loyalty can the teacher maximize his efforts in the learning process.

The objectives designated by the authors of this chapter constitute a basis for unifying the efforts of all science teachers from the

kindergarten through the twelfth grade. They also define the contributions science-teaching can make to the total education of young people.

The Research Scientist Looks at the Purposes of Science-Teaching

ERIC M. ROGERS

We live in a scientific civilization, whether we like it or not. Governors, lawyers, business heads, have to deal with scientists; and every educated person finds his intellectual outlook influenced by science. Yet our science-teaching of nonscientists, in school and college, has built up mistaken views, dislikes, and the common boast, "I never did understand science." Even those students who arrive at college with plans to become scientists usually bring a mistaken picture of science, something like a *stamp collection of facts* or a game of *getting the right answer.*[1]

The first of these attitudes seems to come from a sort of smörgåsbord course of snippets of information; the second, from an intensive training course for passing examinations which do not ask about the student's understanding but simply require him to put the numbers in the right formulas. Neither type of course (in school or college) seems to give students an understanding of science as we find it among scientists. Neither shows students how real scientists work and think, how the facts are gathered, what the laws that emerge are worth, where the formulas come from or what they mean.

Educators who are concerned with giving nonscientists an education in science that will be both lasting and useful are apt to believe that a sense of understanding *what science is* and *how scientists work* is more important than all the rest. Suppose we think of our own children as planning to be nonscientists but taking some science courses as part of their general education. With what questions

1. Parts of this article are drawn from the author's papers on science for general education in college. See "Science Courses in General Education," in *Science in General Education,* chap. i (edited by Earl J. McGrath. Dubuque, Iowa: W. C. Brown Co., 1948); "Block-and-Gap Scheme for Physics Courses," *American Journal of Physics,* XVII (December, 1949), 532–41; "The Good Name of Science: A Discussion of Science Courses for General Education in College," *Science,* CX (December 9, 1949), 599–640; "A Letter to High-School Science Teachers from a College Science Teacher," *Bulletin of the National Association of Secondary School Principals,* XXXVII (January, 1953), 43–49.

should we test the success of such courses? We should hardly be content to ask: How many facts have they learned? Facts are forgotten all too soon. We are more likely to ask: Can they think scientifically? Do they understand what science is about and how scientists go about their work? Have they a friendly feeling toward science and scientists? Are they likely to read scientific books in later life with enjoyment and understanding? Could they enjoy intellectual discussions with scientists? Could they work with scientific advisers in business or government?

But what about preparation for college science? Only a fraction of those who learn science in high school continue with science in college, and, of these, only a small fraction become professional scientists. On those specialists, the colleges lavish special training and care; all the more reason why high schools need not do so, since later training can make good any existing deficiencies. The future scientist can look after himself, if only you will find and encourage him. Yet we do want high-school science to help, in three ways:

1. Give the future specialist a good foundation for later training.
2. Encourage more-able students to choose science in college by giving them a more-genuine example of scientific work in school.
3. Develop the encouraging climate that the young scientist needs by giving all educated nonscientists, including parents, a happier and more-understanding attitude toward science.

All of these persons need good teaching of science; not so much a great wealth of knowledge as *a healthy understanding of the nature of science.* But this is also what the nonscientist needs: a sense of knowledge leading to a sympathy with science and an appreciation of the way scientists work. Given these, how easy to encourage later learning and reading, in either layman or specialist!

The same thing, then, is wanted for all: *an understanding of science;* but the level of knowledge and the speed of teaching need not be the same for all.

In trying to provide better science-teaching, we start by asking what should be our aims and how can we attain them? Here are the answers given by other people:

1. Teaching some facts and principles.
2. Inculcating higher virtues, such as accuracy, critical thinking, scientific honesty, and, more generally, scientific method.

3. Developing an understanding and appreciation of science and scientists, which may last usefully through later life.

Let us look at these three categories of aims in detail.

1. Content *is* useful, in the kitchen, the factory, and in life in general. Any course that aims at really teaching science, not just telling little tales about wonders, must teach a considerable body of facts and principles. But in many courses pupils find the topics crowded and unfinished. Ten years after school, what is left? Certainly not the facts. Facts are soon forgotten or muddled. Even the principles are not clearly remembered. Most of us are loathe to omit large pieces of the usual syllabus, partly because we are afraid to fall behind our colleagues, and partly because we believe all the topics are indispensable. Are they valuable if they are not fully understood and remembered?
2. The attainment of the higher virtues would, indeed, be wonderful. But science-teaching cannot confer these benefits on pupils unless the training given in science classes can somehow be transferred to other fields of study and to life in general. Is this transfer easily made?

   Early in this century experimental investigations by psychologists indicated that there is no transfer. Later studies showed that transfer can occur to some extent, but certainly not as easily as educators and the general public believe. Without such transfer, higher education would seem worthless except for professional training. Fortunately, as shown by later studies, there is some transfer, and it may be considerable under favorable circumstances:

   (*a*) There must be common elements in the field of the training and the field to which we wish such training to transfer; i.e., there must be similarity between influence and influenced functions. For example, if we train a student to weigh accurately in a physics laboratory, it is almost certain that this training will transfer to another physics laboratory and that the student will weigh with accuracy there; it is moderately certain that he will carry the good training to a chemistry laboratory; much less likely that he will carry it to any weighing he does in his own kitchen or in his business; very unlikely that the training will reappear as a habit of being accurate in other activities.

   (*b*) The student develops an emotional attachment (or "sentiment") toward his studies with which he associates feelings of enjoyment, interest, and commitment. The more he enjoys his science and is inspired by its skills and methods, the more he likes discussing its philosophy, the more likely he is to retain the principles taught. A student who develops a *delight* in accurate weighing, making accuracy a minor ideal, may well carry the techniques and attitudes

of seeking accuracy far and wide in his activities, particularly, if he has been made aware of the possibility and value of this wide transfer.

(c) The student is encouraged and given opportunity to generalize. Making a student aware of his gains in one field, and pointing out their applicability to other fields, can make transfer more likely.

3. With the difficulties of transfer in mind, I am doubtful of the "higher-virtue" claims of science-teaching. I reduce my hopes to "giving an understanding of science and scientists." From this, if done with a mixture of hope and enthusiasm, we can expect telling gains.

How can we teach to promote this more realistic aim? *First*, though we teach the same science, or some of it, we may need a change of emphasis, more thorough teaching of the topics treated, instead of descriptions and results; more emphasis on where scientific knowledge comes from, how it is gained, codified, reinterpreted with the help of speculation; more use of rough estimates rather than too much concern for precise measurements; altogether, more emphasis upon creating a feeling for science as a structure of facts, laws, models, or speculations.

Then, I want to urge the reduction of the content of your courses. Reducing the pressure-to-finish-the-syllabus contributes to clear explanation and understanding. Pupils will not suffer from the reduction in content; they will not even be ashamed of patches of ignorance with which they are left because they will emerge with ability and readiness to read more on their own. The principal should not mind, if he knows that genuine science selected from an over-full field is being taught. He would not urge his language teachers to compress five languages into one course. This scheme should not be mistaken for a "smörgåsbord" survey of little topics. Far from it; the treatment of what is taught should be so thorough that pupils learn it with a proud feeling of full possession.

Next, laboratory work on a simple scale should be provided for all. How can the average citizen understand the scientist's experimenting if he does not himself experience some of its trials and delights? Laboratory work should be genuine experimenting and not a hurried following of prescribed exercises. Fewer experiments will teach far more if the student does them himself, as a "scientist for a day."

The School Administrator Looks at the Purposes of Science-Teaching

JOHN H. FISCHER

The new interest in science has improved the setting for science-teaching and has accentuated the problem of helping *all* children acquire some knowledge of science and an appreciation of the part it plays in their lives.

If it were only necessary to decide whether to teach the rudiments of science to everyone on a mass basis or to identify the gifted few and carry them as far as they can go, our task would be relatively simple. To the public school system, however, no such choice is available, for the two jobs must be tackled and carried forward simultaneously. Because we depend so heavily upon science and technology for our survival and progress, we must produce competent specialists. Because we are a democracy, whose citizens are the ultimate policy-makers, large numbers of us must be educated to understand, to support, and, when necessary, to judge the work of the experts. The public school must educate both producers and consumers of scientific services.

Implicit in all good education is a sound balance among the branches of knowledge which contribute to effective performance and wise judgment. Such balance is defeated by overemphasis on any one field. The need today goes beyond simply adding more science to the schedule. We need programs planned to reflect the place of science in our culture and to encourage the mastery of scientific materials and disciplines in terms appropriate to the maturity of the pupils.

This question of balance involves not only the relation of the natural sciences, the humanities, and the arts but also relative emphases among the natural sciences themselves. The new interest in the physical sciences and mathematics should not be allowed to obscure the relevance of the biological fields. Indeed, it is arguable that basic biology and its relation to agriculture and health may have greater significance for the teaching of science than many of the advances in nuclear physics.

Similarly, balance must be maintained between the current and the classical. The continuous publicity given to the expanding fron-

tiers of science and the discovery of new knowledge should not be allowed to divert attention from the basic materials of established validity which must continue to form the backbone of standard courses for beginners. Skilful teachers usually relate basic materials to current affairs, but they do not rely solely upon the latest headlines as they plan their teaching.

The widespread readiness to move forward in science education is retarded by an equally widespread uncertainty as to which direction is forward. In formulating objectives, identifying curriculum problems, marshaling resources, and combining the contributions of specialists in science and of other educators, the burden of leadership falls upon the administrator. Those with special competence and concern for science education can help the administrator understand the nature of the objectives, the issues to be faced, and the means available to deal with them. The administrator will be able to do his job better if he seeks the guidance of specialists.

The Institute Scientist Looks at the Purposes of Science-Teaching

J. W. BUCHTA

Not because there are satellites following their elliptical orbits about the earth nor because other nations have given emphasis to training in technology and science, and not because of any alteration of our scale of values, should it suddenly be declared that science must occupy the commanding position at all levels in our educational system. Nevertheless, we live in an environment molded by the applications of science, and we believe some of the processes used in arriving at conclusions in science have a relevance to our thinking and, indeed, to our behavior in other phases of life. Hence, education in science should be a part of the intellectual heritage of all.

The gross divisions of academic interests, namely, the humanities, the social sciences, and the natural sciences, are not of purely arbitrary nature. In the humanities we recognize values; values established by man himself. In fact, all of the usual subdivisions of the humanities, the arts, literature, languages, and philosophy, are products of human activities. They have meaning only in terms of human kind. Their very existence, their growth and evolution de-

pend upon man. The social sciences, while not entirely independent of geographical and climatic factors, for the most part involve a world that is "man made." There is a great physical universe, an environment in which we live, that is not our handiwork. The decisions with respect to what is right or wrong, correct or incorrect in the natural sciences, do not rest with man as the final arbiter. Nature is the umpire in this game. Man finds himself in a world of matter and radiation with organizations that, in some instances, result in life; and at the pinnacle is "man thinking." In all of this he asumes order; in fact the first article of faith of the scientist is that there is order in the universe, that nature is not capricious. To find this order is the goal of the scientist.

Science does not attempt to explain, in the ultimate sense of that word. It does, however, attempt to give a comprehensive description of the universe around us. In so doing we need not detract from nor destroy any profound respect for things spiritual. Indeed, the grand view obtained through science may deepen and make more secure our beliefs in a realm not reached by science.

Just as a youngster learns to use words and to know their meaning, and just as he learns that he is a social being whose rights end where another's begin, so should he learn of the natural world about him. For this purpose he first needs facts. These are accumulated through our senses and the extensions we give them by use of instruments. The habit of observation and the development of curiosity, coupled with an objective acceptance and appraisal of observations, should be among the chief objectives of science-teaching. At an early age, the habit of seeking for information, whatever that information may be and however it may change any previously acquired ideas, should be inculcated and developed so that this scientific habit becomes a common behavior instead of being looked upon as something very special.

Because the time, resources, and abilities of each individual are limited, we must accept many findings in science as they are stated by the expert. But the spirit of authoritarianism should never enter science. We must always be in the position to say and believe that given time and resources we, too, could find the answer to our question, the answer we now accept from others. But in the schools, whenever possible and especially at the elementary level when many

questions are asked, we hope the teacher may answer, "Let's find out," and not depend on the book or other authority unless no other method of obtaining an answer is possible. If this spirit of science is acquired during the first dozen years in school, we need not fear for the future of science.

Finally, mathematics and quantitative thinking should not be neglected. It should be emphasized that the lack of preparation in mathematics will often make it impossible for a student to pursue a career in science. Therefore, students in science classes should be provided with many opportunities to describe their work in quantitative terms.

The College Dean Looks at the Purposes of Science-Teaching

VERNON E. ANDERSON

It would seem incredible today to have to declare that the study of science is "unavoidable," as did the authors of the National Society's Forty-sixth Yearbook.[2] It is such an interwoven part of the fabric of the culture that the general public is in many ways aware of its importance. The degree of awareness differs. It is not always accompanied by an understanding of how science affects the lives of mankind, their political institutions and human relationships, and what scientific-mindedness means.

Changing times demand a change in any kind of education. The question becomes not so much the importance of science education but its importance for all as a part of their general education, for the consumers as well as the producers of scientific knowledge.

It is quite clear that not all spokesmen for increased or improved science education have an equally comprehensive understanding of what is being done; nor do they see eye to eye on how it should be done. But they are more likely to agree on ends than on means.

Criticisms seem to suggest that the present objectives are not fully acceptable. Perhaps, instead, what is needed is a clarification of purposes as to their meaning for practice and a re-examination of the emphasis on various aims. Moreover, it is important that science

2. *Science Education in American Schools*, p. 17. Forty-sixth Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by the University of Chicago Press, 1947.

teachers identify students for whom present objectives are to be emphasized.

As the educator looks at science education in its historical perspective, there are certain aims stressed in the earlier writings with which he cannot agree, as, for example, the generalized training of the mind. But he finds no quarrel with the emphasis on scientific methods and procedures, with the understanding of principles and the interpretation of generalizations, or with sincere attempts to make science functional in the lives of students; nor does he belittle an increased interest in science, the development of scientific attitudes, the overcoming of superstition and prejudice, the tolerance of uncertainty, the development of original and independent thinking, or the acquisition of knowledge about scientific phenomena.

One might question: What about the college preparatory aim? But what is there about these objectives that does not facilitate preparation for further study of science or further study of any kind? Does college preparation mean "getting physics off" with a sigh of relief? Does it mean narrowness of preparation in mathematics and the physical sciences to the exclusion of the humanities and social sciences? Instead, it is the inquisitive mind, the interest and the accompanying background of information, the problem-solving and research skills, the understanding of scientific concepts, and the fluency with which to express these concepts and ideas that are prized by the college professors of science.

Indeed, it is the teaching of science toward change of behavior of this nature which needs emphasis. We need to develop persons with questioning and questing minds, those with curiosity; to stimulate persons who are dissatisfied with pat solutions or the status quo, those who dream, who can conceptualize, who use reflective thinking in solving problems, and those who make fewer snap judgments based on their own and their immediate culture's prejudices.

Beyond this, we need others who use the method of science to a high degree of perfection, who can project themselves beyond the boundaries of their experiences, who can originate, who act like scientists.

The teaching of science that aims at changes of behavior looks quite different from that which settles for shoddy goals, such as covering the book or learning the material for a test. The results

must become a part of a person if they are to make him one who really understands and speaks for science and cherishes the scientific attitude.

The recent emphasis on science and mathematics has stimulated imaginative experimentation with ways of assisting students with special abilities to make the most of their potentialities. Those who can run are allowed, encouraged, and helped to do so. Seminars, advanced courses in physics and chemistry, an extra period in which the teacher works with individuals who will go as far and as fast as they can, resource persons, and those who work in research laboratories are some of the means used. Such programs imply that the purposes for the teaching of science may vary, at least in intensity, for students of different interests and abilities.

But science can no longer afford to be taught only in specialized courses for the college-bound and in survey courses for those of lesser ability. All students need a general education that leads to an understanding of the social implications of scientific advancement. The knowledge of science is an important contributor in this day to the solution of social issues.

It is important that the study of science should be an adventure that employs the rich resources at hand in the classroom, in the library, and in the community. It should seek to encourage the nonconformist and to question practices that lead to parroting and stultifying knowledge. Then science will become the great adventure and challenge that it richly deserves to be. These are the goals of the educator.

The Industrial Researcher Looks at the Purposes of Science-Teaching

GUY SUITS

Science education for the American citizen has two basic functions to perform. One is to train specialists for a career in science; the other is to broaden the horizon of the nontechnical citizen by giving him some familiarity with the content and disciplines of science. As human endeavor has advanced farther and farther into technology, the need for both functions of science education has increased. A reappraisal of our educational system in the light of recent developments does not reveal any change in the *basic func-*

tions of science education, but it does emphasize the vastly increased importance of *both* of these functions.

The need for technically trained manpower includes two classes of specialists: research scientists who contribute to the body of knowledge and understanding of nature that is the source of all technology; and applied scientists and engineers who adapt technical knowledge to human needs. Advances on the frontier of many fields are made by a relatively small number of highly qualified specialists who possess an unusual degree of originality and desire to penetrate the unknown. The chief motivation of these individuals appears to be an avid curiosity and an urge to understand natural phenomena. Research scientists of this kind are found largely among university scholars, with a smaller number in industrial and other nonacademic institutions. New scientific knowledge is an essential resource for an advancing technology.

In order for technology to provide a continuous supply of applications of science in new products, processes, and materials, it is essential to have technically trained people who work in applied research and engineering development. These specialists, some of whom are trained in science and some in engineering, have as a primary motivation the application of scientific discoveries and their incorporation into salable products. The need for specialists in this category far outruns in numbers the need for research scientists of the type mentioned above. Both groups, however, are essential in a technological civilization.

While there is a practical limit to the *number* of technically trained people that can be effectively utilized at any given time, there is never an oversupply of *first-rate* technicians. Hence, the great challenge to our science-education program is raising the average level of scientific competence. Scientific leadership depends upon the creativity of a relatively few individuals possessing rare talent that is fully developed.

The need for broadening the horizon of the nontechnical person is a concomitant of the need for more specialists. The technological supremacy of our country rests upon a foundation that is not more substantial than the level of technical appreciation of our citizenry. This fundamental fact places a responsibility upon our science-edu-

cation program to raise the level of understanding of the contributions of science among those who will not themselves contribute directly through scientific careers. Schools must provide a good general scientific training for everyone if our technological stature is to rest upon a firm foundation.

In viewing science-teaching, the industrial research scientist can recognize a tremendous change over the past seventy-five years. Primarily, this change is a reflection of the culture or social structure into which research results are fed and on which industrial research depends. Seventy-five years ago, research was an intellectual activity carried on in universities with relatively few of its results having a significant effect. Now, however, technological devices are all around us, and new discoveries in academic or industrial research laboratories soon influence the lives of all citizens. The whole fabric of American society is a pattern woven on the basic warp of technological achievement, and political decisions on the international scene must be guided by an appreciation for scientific and technological opportunity and achievement. Hence, in order to comprehend his environment, the ordinary citizen, be he a scientist or not, must have some education in the field of science.

A reappraisal of our science-education program in the light of its two basic functions and the present technological environment leads us to several pertinent considerations. Probably the first consideration is the content of our basic science courses, which demands close scrutiny. The selections of material should be consistent with the changing emphasis and must take into account the limitations of time.

Another important aspect of science-teaching embraces the problem of interesting students in science and its corollary, measuring scientific aptitude, so that effective guidance can be assured. It is not good educational practice to divert students from fields in which they might do well into others in which they will do poorly. In our preoccupation with the need for scientific manpower, we must not make the crucial mistake of sacrificing the equally important need for creative manpower in other fields such as the humanities, the arts, and political science.

The Behavioral Scientist Looks at the Purposes of Science-Teaching

RALPH W. TYLER

Intelligent and responsible behavior by human beings is dependent to a large degree upon their perception of the world in which they live as one which they can understand and in which their actions make a difference. Apathy, irresponsibility, and, in many cases mental breakdown result from perceptions of the world as meaningless, or one in which the individual person has no way of controlling the forces which impinge on him. Because science is ever at work constructing a comprehensible and orderly system of explanations for natural phenomena and building a basis for intelligent control and utilization of the natural world, it provides an important resource for the education of youth. The use of science in this way is significant and essential for every boy and girl regardless of his special interests and gifts and his occupational plans. Hence, it is a necessary part of general education. In addition, science can and should make a major educational contribution to those pupils who have special interests and abilities which may lead to specialized study and work in science, engineering, or technology.

Science and technology are much more central in contemporary life than they were even thirty years ago. New concepts, new generalizations, new applications are being evolved at a rapid rate. Hence, the individual today is not able to understand his natural world and to take intelligent responsibility for his actions in controlling and using natural phenomena if he merely remembers the explanations presented in a textbook when he was in school. He must understand science as a continuing process of inquiry, not as a set of firm answers to particular questions. When science is taught as a final set of answers, the student is not prepared for intelligent and responsible behavior, and the changing world of nature and technology is as confusing to him as to an aboriginal savage.

The common concern with teaching students the "right answers" not only fails to give proper emphasis to science as a powerful means of seeking understanding but it also fails to make meaningful many of the concepts and generalizations that are taught. Concepts gain meaning to the student as he uses them in trying to find in a

complex and unordered phenomenon some few significant aspects that can be studied more intensively. Generalizations gain meaning to him as he uses them in seeking to explain some perplexing phenomenon. A major objective, then, in science-teaching is to help students develop the ability to carry on the whole process of scientific inquiry, including raising questions, identifying particular problems growing out of these questions, suggesting possible explanations, devising ways of testing these explanations, making relevant observations and collecting relevant data, interpreting the data, and restating the explanations and the new questions and problems that result from this cycle of inquiry.

Because the individual today is often impressed by the futility of his own efforts in a world so complex and heavily populated, science-teaching should include some attention to problems of concern to the student in which scientific inquiry can yield constructive courses of action. This kind of educational experience helps to give the individual confidence that intelligent problem-solving can help him control his environment so that he need not be helpless in the midst of forces beyond his control. In this connection, for example, problems relating to his own health and the community's health and to effective utilization and conservation of natural resources provide opportunities for the employment of science concepts and generalizations as well as a chance to devise courses of action which are likely to make a difference.

This emphasis upon science as a means for students to gain understanding and to solve problems implies several other objectives. If students are to continue to seek scientific understanding long after graduation, they need to develop interest in science, interest in seeking ever more adequate understanding, interest in reading science materials, and interest in other activities involved in scientific inquiry. They need to develop an objective and critical attitude toward generalizations and explanations in science. They need to become familiar with dependable sources of information in fields of science.

From the standpoint of requisites for intelligent and responsible behavior, it is also important for every boy and girl to understand the kinds of questions with which science deals and the kinds of questions which it does not seek to answer. The world, the universe,

life, man, and his products represent so broad and complex an array of objects of study that no single set of concepts or of methods of inquiry is adequate to deal with them all. Yet, a single-minded enthusiasm for science or for any other kind of study may lead pupils to try to evolve a world picture in limited dimensions and to take actions which are unintelligent and often self-defeating.

The behavioral scientist tends to think of education primarily in terms of the process by which the individual is aided to bring more fully into play the potential of intelligent and constructive behavior which he possesses. Hence, he is likely to think of science education as the extension and more adequate development of children's curiosity through the processes of exploration and learning by experience. In these terms, science education should begin in the primary grades and should represent a gradual and sequential development of scientific inquiry. Elementary science, although less complex and involving few specialized techniques, should be as much a proper illustration of scientific inquiry as college science. Questions arise, more specific problems are identified, possible explanations are considered, and observation rather than an answer given by an adult authority is used as a test of validity.

Finally, the behavioral scientist is concerned with the long-range effects of each area of education in terms of its increasing rather than decreasing the flexibility, adaptability, and creativity of human behavor. The likelihood of human survival and the quality of human life are dependent on these traits. Hence, science education should avoid boring routine and emphasize new perspectives, new problems, the satisfactions that come from science study. When many students find science distasteful, dull, or incomprehensible, something is wrong. Science education should be, and can be, a way of opening new vistas to students and of finding satisfaction in imaginative and constructive use of their intelligence.

Summary

PAUL DeH. HURD

The objectives of science-teaching as they appear in educational literature have changed little in the past twenty-five years. On the other hand, there have been changes in the nature of the science taught; for example, the sciences have become more unified and

have gained an important position in world affairs. These factors suggest the need to re-think the purposes of teaching science in schools.

Recently there has been much criticism of science-teaching. Some scientists have been concerned that science was not being taught either as understanding or as enterprise. They have thought that science-teaching should reflect the nature of science, and it should harmonize with the scientific point of view. The lack of social orientation in science-teaching and the failure to teach modern science have concerned other groups.

The objectives of the teaching of science are essentially the same from the elementary through the high school. The degree of attainment and the level of competency vary according to the development, interest, and abilities of young people. We cannot expect that every objective will be achieved by all students, that the rate of achievement will be uniform, or that everyone will reach the same level of understanding. This suggests that the objectives of the student who is oriented to a science career and those of the college-bound student will be different from those of other pupils.

Many criticisms directed toward the objectives of science-teaching are actually a censure of classroom procedures which fail to realize those objectives; for example, methods which demand too many facts, too little conceptualizing, too much memorizing, and too little thinking.

The following listing of objectives provides a model by which the teacher may orient his thinking in developing his own purposes for teaching science.

UNDERSTANDING SCIENCE

There are two major aspects of science-teaching; one is knowledge, and the other is enterprise. From science courses, pupils should acquire a useful command of science concepts and principles. Science is more than a collection of isolated and assorted facts; to be meaningful and valuable, they must be woven into generalized concepts. A student should learn something about the character of scientific knowledge, how it has been developed, and how it is used. He must see that knowledge has a certain dynamic quality and that it is quite likely to shift in meaning and status with time.

The pupil needs at each grade level to acquire a background of ordered knowledge, to develop an adequate vocabulary in science for effective communication, and to learn some facts because they are important in everyday living, such as knowledge that is useful in maintaining health, promoting safety, and interpreting the immediate environment.

Recent theories and new knowledge should have priority in science-teaching when they are significant and can be made understandable at a specified grade level. The generalized concepts selected for teaching should be those which tend to explain or involve many science facts.

PROBLEM-SOLVING

Science is a process in which observations and their interpretations are used to develop new concepts, to extend our understanding of the world, to suggest new areas for exploration, and to provide some predictions about the future. It is focused upon inquiry and subsequent action.

Methods for solving problems in science are numerous. There is no one scientific method; in fact, there are almost as many methods as there are scientists and problems to be solved. Inevitably the details of scientific investigation are seldom the same for any two problems. What is done is highly flexible and quite personal. Incentive, intuition, the play of imagination, fertility of ideas, and creativeness in testing hypotheses are important parts of the process. The methods of science are something more than measurement, laboratory techniques, and data processing followed by logical deductions. Sometimes they are not very logical, but the search for truth is always present. Presenting problem-solving as a series of logically ordered steps is simply a technique to isolate the critical skills and abilities and to give them special attention in teaching.

A process of inquiry involves careful observing, seeking the most reliable data, and then using rational processes to give order to the data and to suggest possible conclusions or further research. At higher levels of achievement the student should be able to establish relationships from his findings, and in turn to make predictions about future observations.

THE SOCIAL ASPECTS OF SCIENCE

Young people need to understand the dependence of our society upon scientific and technological achievement and to realize that science is a basic part of modern living. The scientific process and the knowledge produced cannot be assumed to be ends in themselves except for the classical scientist. For him the pursuit of new knowledge is a professional effort and any lack of social concern on his part may be accepted. But a liberal education has a wider orientation, particularly at precollege levels. A student should understand the relation of basic research to applied research, and the interplay of technological innovations and human affairs. More of technology than science will be involved in social decision, both are important in public policy.

APPRECIATIONS

A student with a liberal education in science should be able to appreciate:

1. The importance of science for understanding the modern world.
2. The methods and procedures of science for their value in discovering new knowledge and extending the meaning of previously developed ideas.
3. The men who add to the storehouse of knowledge.
4. The intellectual satisfaction to be gained from the pursuit of science either as a scientist or as a layman.

ATTITUDES

The knowledge and methods of science are of little importance if there is no disposition to use them appropriately. Open-mindedness, a desire for accurate knowledge, confidence in the procedures for seeking knowledge and the expectation that the solution of problems will come through the use of verified knowledge, these are among the "scientific attitudes."

To understand the scientist is also to understand some of his attitudes, such as the desire to know and to discover, a curiosity about the world, the excitement of discovery, and the desire to be creative.

CAREERS

Science instruction should acquaint students with career possibilities in technical fields and in science-teaching. A continuous

effort should be made to identify and motivate those who develop special interests. They should be given opportunities for some direct experience of a professional nature and a perspective of the fields of science.

ABILITIES

Science as a field of study is characterized by a moving frontier and an ever increasing amount of knowledge. Young people need to acquire those skills and abilities which will enable them to assume responsibility for expanding their own learning. Some of these skills and abilities are:

1. Reading and interpreting science writings
2. Locating authoritative sources of science information
3. Performing suitable experiments for testing ideas
4. Using the tools and techniques of science
5. Recognizing the pertinancy and adequacy of data
6. Making valid inferences and predictions from data
7. Recognizing and evaluating assumptions underlying techniques and processes used in solving problems
8. Expressing ideas qualitatively and quantitatively
9. Using the knowledge of science for responsible social action
10. Seeking new relationships and ideas from known facts and concepts

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CHAPTER III

How the Individual Learns Science

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Important among the objectives of science teaching are the learning of concepts, generalizations or principles, and scientific methods and attitudes, This chapter deals with the ways in which pupils learn these concepts, principles, methods, and attitudes, how aptitude and achievement in science can be evaluated, and, finally, a point of view about learning science.

The Development of Scientific Concepts

Northrop interprets "concepts" as words that have been given concise meanings; accordingly, he defines science as the discipline which conveys the techniques for giving precise meanings to significant words. To some persons a concept is simply a thought or an idea. In any case, the clarity and completeness of one's concepts are measures of success in learning.[1] Russell believes that concepts do not really, by themselves, solve any problems, but he argues that they are necessary for thought and for communication.[2]

Concepts are abstractions which organize the world of objects and events into a smaller number of categories. These, in turn, can be organized into hierarchical systems, thus extending organized knowledge. Although the term *concept* is often restricted to ideas descriptive of classes of objects or events, such as "tree" or "motion,"

1. F. S. C. Northrup, "The Problem of Integrating Knowledge and the Method of Its Solution," *The Nature of Concepts: Their Interrelation and Role in Social Structure,* p. 25. Proceedings of the Stillwater Conference conducted by the Foundation for Integrated Education, Inc., and co-sponsored by Oklahoma A. & M. College. Stillwater, Oklahoma: Oklahoma A. & M. College, 1950.

2. David H. Russell, *Children's Thinking.* New York: Ginn & Co., 1956.

generalizations and principles may also be treated as concepts. A generalization or principle differs from a simple concept in that it states some kind of relationship between two or more abstractions, objects, or events. The statement that "for every action there is an equal and opposite reaction" is an example of a generalization involving relationship among three concepts, "action," "equal," and "opposite."

Scientific concepts include mathematical concepts, concepts of space, time, and weight, as well as concepts specific to the various areas of science. Concepts of measurement are dependent upon concepts of number and the development of measuring procedures. Since science depends to a large extent upon measurement, scientific concepts develop rather slowly.

In addition, the learning and understanding of science is complicated by the introduction of concepts of objects which are postulated or imagined. Such ideas as the gene, the atom, and the electron, which were invented to explain observations, create difficulties for the beginning student who often has trouble distinguishing between concepts derived from perception such as "egg" and an imagined concept such as "gene." Similarly, it is difficult to distinguish generalizations which are concerned with concepts derived from perception, such as "Elements unite chemically in a definite proportion by weight," from theoretical statements, such as "All elements are composed of atoms."

Again, difficulty in the mastery of scientific concepts may arise from common-sense meanings, which are often quite different from precise, scientific meanings. The term "force" is one example. The scientific concept is more restricted than the common-sense one.

One of the problems which confronts the teacher is that of ascertaining whether or not a student has grasped a concept instead of a generalization. There are two different methods of measuring the level of concept attainment. One involves defining the word or stating the generalization; the other involves the identification of objects or events by members of the class. The results of these two methods do not agree.[3] A student may be able to define force without being able to give an example, or he may memorize the relation-

3. Donald M. Johnson, *The Psychology of Thought and Judgment.* New York: Harper & Bros., 1955.

ship but be unable to use it. On the other hand, another student, though lacking in knowledge of the precise formula, may manifest some understanding of the general relationship. Deductions from vaguely defined or imprecise generalizations are entirely possible. Some of our teaching practices seem to assume that rote memory and recall of a definition or generalization demonstrate mastery of the concept, but unless the concept is seen by the individual as a unifying element in many different experiences it is doubtful that a meaningful concept could have been acquired. Harlow[4] points out that broad concepts or principles do not arise from learning or over-learning a specific problem; breadth rather than intensity appears to be the key to concept formation.

What, then, is the best method of acquiring concepts? There is some evidence to indicate that for relatively easy material the inductive method of deriving the concept out of many specific examples is adequate. For difficult material, or when the possibility of error in concept formation is great, it appears that a deductive approach in which the presentation of the concept is followed by extensive application is preferable. A combination of the two methods appears to be superior to either method alone. However, these conclusions are tentative and require more research.

Since concepts and generalizations may be formed in various ways, such as from perceptions, from communicating with other people, from inference or content, or from problem-solving situations, it is not surprising that there are many sources of error in concept formation. According to Russell, the causes of errors in concept formation are:

1. Errors in the percepts from which the concepts emerge.
2. Confusion between images and memories aroused during recall.
3. Lack of experience to check or validate the generalizations reached.
4. Set or suggestibility caused by certain features of the environment being more influential than others equally important.
5. Overconfidence in the results of one's observations and conceptual thinking.[5]

Concepts arising from perceptions are apparently more easily formulated than abstract concepts. Likewise, undifferentiated and

4. W. F. Harlow, "Thinking," in *Theoretical Foundations and Psychology*. Edited by H. Nelson. New York: D. Van Nostrand & Co., 1951.

5. David H. Russell, *op. cit.*

discrete concepts are more readily grasped than differentiated and organized concepts. The order of acquisition of concepts seems to be related to the level of abstraction of the idea. For example, such an order of acquisition as concrete object, spatial form, and mathematical relationship is found in the atomic molecular theory.[6] The concept of the atom as a unit of matter is acquired with relative ease; the idea of molecular structure is somewhat more difficult; while the actual deduction of various atomic weights from the atomic theory is an extremely difficult operation for most students.

Since concepts which arise from perceptions are formed more readily than more abstract concepts, the actual manipulation of materials should facilitate conceptualization. Davidson[7] checked this inference experimentally and suggested that grouping materials aids in the fixing of concepts. Any arrangement of materials which emphasizes the common characteristics and minimizes the irrelevant characteristics apparently helps in concept formation. Numerical concepts are made easier by illustrating them in spatial or graphic form. If they can be illustrated by use of visual models, this further facilitates the ease of conceptualization.

Learning Critical Thinking

The wide usage of a word often clouds its meaning and leads to the addition of qualifying phrases or to the use of alternative terms. *Thinking* is such a word. *Critical, reflective, productive,* and *creative* are such qualifiers. *Problem-solving, judgment,* and *scientific method* are much used alternatives, each having presumably different but unclear shades of meaning. Lacking adequate research, the interrelationships of critical (considered as a synonym of careful) thinking, creative thinking, judgment, and scientific method can only be examined on rational grounds.

THE NATURE OF CRITICAL THINKING

Critical thinking is commonly analyzed into steps which suggest the nature of the process and which must not be regarded as discrete and sequential. They include:

6. Donald M. Johnson, *op. cit.*

7. B. S. Davidson, "The Effect of Symbols, Shift, and Manipulation upon the Number of Concepts Obtained," *Journal of Experimental Psychology,* XX (1952), 285–96.

1. Recognizing and defining a problem.
2. Clarifying the problem by making appropriate definitions, distinguishing between facts and assumptions, and collecting and organizing relevant information.
3. Formulating possible explanations or solutions (hypotheses).
4. Selecting one or more promising hypotheses for testing and verification.
5. Stating tentative conclusions.

Implied in these steps are certain attitudes, such as doubt or a degree of skepticism of too quick or authoritarian explanations, a curiosity as to the why of things, intellectual honesty, suspended judgment, and belief that phenomena are subject to explanation.

Discussions of the scientific method[8] have repeatedly led to steps almost identical with those just enumerated, and attempts to elaborate the scientific attitude have resulted in statements of qualities similar to those mentioned. Science proceeds through making careful observations, by using relevant knowledge to make hypotheses and inferences and, finally, by seeking corroborative evidence. Critical thinking and the scientific method are apparently closely related; many persons see them as simply different names for the same intellectual activity.

The common use of "steps" and of "method" referring to intellectual activity may seem to rule out creativity, for creativity implies insight and originality which transcend methodical plodding through a series of steps. Yet every really significant thought process contains a creative element. The formulation of a hypothesis, the making of an inference, or the venturing of a new theory are essentially creative tasks. Observation is a creative act for the individual who perceives something not previously noted by himself or by others. Creativity, even in the arts, is often largely trial and error, although a brilliant rationale may be presented later. So, too, the "steps" of the scientific method are easier to find in retrospect. Creative thinking, like critical thinking, involves attitudes. The creative individual must have some skepticism of existing ideas or even a disdain for them; he must escape the social pressures toward conformity.

8. Oreon Keeslar, "A Survey of Research Studies Dealing with the Elements of Scientific Method as Objectives of Instruction in Science," *Science Education*, XXIX (October, 1945), 212–16.

SITUATIONS AND METHODS WHICH EVOKE CRITICAL THINKING

There are various ways to study critical thinking. In one method, the observed product of thought implies stimulation of mental processes. Others have explored their own thoughts by introspection or retrospection. Logicians see the rules of logic as descriptive of systematic thinking, although these rules are more useful in presenting results of thinking than in experiencing the process.

The first two of these approaches to critical thinking—the inferring of mental process and the exploring of the process from original thinking to its product—have not yielded definite conclusions as to how the mind works. This leads to doubt that critical thinking is directly teachable. Rather, the task is to develop a favorable attitude and to provide examples and experiences which permit and encourage critical thinking. In contrast, those favoring an approach through logic would have the student learn the principles and techniques of logic and develop the habit of applying them. Pupil discovery of these principles is sometimes emphasized. This conception of critical thinking provides an effective pattern for analyzing the thinking of others, but it makes no allowance for the creative element of planning and hypothesis formulation required in original thinking. Moreover, the logical organization of the process and its results is often literally an afterthought.

It is not surprising that no simple prescription for teaching critical thinking exists. This lack, coupled with reverence for the mastery of information, leads to disregard of the ability as a formal goal of teaching. Yet there are some definite principles for encouraging critical thinking. Critical thinking must start with a problem which holds some interest, which is within the ability of the students, and for which the students do not know the answer. Such problems may arise fortuitously out of student experiences in or out of the classroom or they may be "planted." Failure to find appropriate problems is usually an indication of preoccupation with giving answers.

Relatively simple problems for which explanations are easily found must be followed by more difficult ones wherein the student learns that even errors and false leads may be productive if only they are viewed in the proper light. Such student projects as those described

by Woodburn illustrate some of these possibilities.[9] Reading about the projects of practicing scientists, such as the attempt to explain Crater Lake or the search for a new refrigerant, will also give the student some insight into how scientists work. Brief, readable reports of these and other investigations are available for this purpose.[10] Such reports give a far different impression of science than do most textbooks which concentrate on presenting the ultimate findings. In a way, too, such reports provide models which encourage and guide the student in thinking about his own projects.

CAN CRITICAL THINKING BE TAUGHT?

The effect of emphasis on critical thinking or the scientific method in particular courses has been studied, and the results in many cases have been positive in that improvement in classes planned around the objective has been demonstrated to be greater than in classes taught with more traditional emphases. Usually the increase in knowledge is equal to or greater than that found in classes taught with content emphasis. The extent to which the increased ability is more broadly applicable to problems in other courses and in life is less certain, for no example of concentrated attention to the objective throughout an entire curriculum over several years has been reported. Nevertheless, the conclusion that students can learn to think more critically if appropriate instruction is provided seems to be justified.

Learning Scientific Attitudes and Methods

VIEWS AS TO THE NATURE OF SCIENTIFIC ATTITUDES AND METHODS

In the present century scientific methods and attitudes have been emphasized, particularly by Dewey, as objectives of formal education.[11] Many articles and investigations on the nature of scientific method have been published since Dewey's analysis. An inspection of this literature leads one to assume that such phrases as "scientific methods," "methods of science," "scientific thinking," "problem-

9. John H. Woodburn, *Encouraging Future Scientists: Student Projects.* National Science Teachers Association, Future Scientists of America Bulletin. Washington: National Education Association, 1958.

10. *If You Want To Do a Science Project.* National Science Teachers Association, Future Scientists of America Bulletin. Washington: National Education Association, 1955.

11. John Dewey, *How We Think.* Boston: D. C. Heath & Co., 1933 (revised).

solving," and "critical thinking" mean much the same and may be used interchangeably without undue confusion.

There developed through the years an interpretation that there was one scientific method with definite steps to be followed in a sequential order. Conant[12] and others have pointed out that this is not an acceptable interpretation. At present, most writers on this subject feel that there are many ways to solve problems scientifically and that no one way is necessarily typical of scientific thinking. It is also to be noted that the methods of science do not necessarily produce a successful solution to every problem.

Some writers on scientific method emphasize the inductive process; others the deductive process. However, it seems reasonable to infer that both processes are involved, at least in certain kinds of problems. It has been argued as to whether scientific methods are largely empirical or largely theoretical. There appear to be learning activities that are mainly empirical and descriptive, others that are highly conceptual, and still others in which theory and trial and error are both employed.

SOME REPRESENTATIVE SCIENTIFIC ATTITUDES

The first comprehensive study to be published with respect to scientific attitudes was Curtis's[13] analysis. Noll's[14] list included such habits as those of intellectual honesty, open-mindedness, and suspended judgment. Other investigators have cited such manifestations as freedom from bias, looking for cause-and-effect relationships, curiosity, and criticalness. Extensive lists of scientific attitudes are to be found in the investigations of Crowell,[15] Ebel,[16] and Lampkin.[17]

12. James B. Conant, *On Understanding Science*. New Haven, Connecticut: Yale University Press, 1947.

13. Francis Day Curtis, *Some Values Derived from Extensive Reading of General Science*. Contributions to Education, No. 163. New York: Bureau of Publications, Teachers College, Columbia University, 1924.

14. Victor H. Noll, "Measuring the Scientific Attitude," *Journal of Abnormal and Social Psychology*, XXX (July–September, 1935), 148.

15. Victor Crowell, "The Scientific Method," *School Science and Mathematics*, XXXVII (May, 1937), 525–31.

16. Robert L. Ebel, "What Is the Scientific Attitude?" *Science Education*, XXII (February, 1938), 75–81.

17. R. H. Lampkin, "Scientific Attitudes," *Science Education*, XXII (December, 1938), 353–57.

COMPONENTS OF SCIENTIFIC METHODS

As indicated previously, several different phrases have been employed to designate the methods of science. It appears from an examination of the literature that such phrases refer to some common components. The components which seem to be most frequently mentioned are: recognition of problem, collection of relevant data, formulation of hypothesis, testing of hypothesis, and drawing conclusions.

The interested investigator should consult the works of Downing, Crowell, Keeslar, and Lampkin[18] for detailed treatments of the methods of science. The individual interested in setting classroom situations for the direct teaching of the attitudes and methods of science and for the testing of such attributes should also find the writings[19] of Barnard, Obourn, and Burmester worth while.

Research studies have indicated that the acquisition of scientific methods and attitude is facilitated by instruction. The evidence as to the relative effectiveness of direct as opposed to indirect teaching favors the former. Studies, with some notable exceptions, show that although there is a positive correlation between the amount of factual knowledge acquired through science training and the ability to exhibit some scientific attitudes,[20] teaching subject matter alone does not produce significant changes in attitude nor measurably train in scientific method.[21] A few thoughtful studies to the contrary, the

18. Elliott R. Downing, "The Elements and Safeguards of Scientific Thinking," *Scientific Monthly*, XXXVI (March, 1928), 213–43; Crowell, *op. cit.;* Keeslar, *op. cit.;* and Lampkin, *op. cit.*

19. Darrell Barnard, "The Lecture-Demonstration versus the Problem-solving Method of Teaching a College Science Course," *Science Education,* XXVI (October–November, 1942), 121–32; Ellsworth S. Obourn, "An Analysis and Check List on the Problem-solving Objective," *Science Education,* XL (December, 1956), 388–92; Mary Alice Burmester, "Behavior Involved in the Critical Aspects of Scientific Thinking," *Science Education,* XXXVI (December, 1952), 259–63.

20. Sam Strauss, "Some Results for the Test of Scientific Thinking," *Science Education,* XVI (December, 1931) 80–93; Otis W. Caldwell and Gerhard E. Lundeen, "Students' Attitudes regarding Unfounded Beliefs," *Science Education,* XV (May, 1931), 246–66; P. P. DeWitt, "Attitudes Related to the Study of College Science," *School Science and Mathematics,* XXXIX (June, 1939), 552–57.

21. Rosalind M. Zapf, "Suggestions of Junior High School Pupils," Part II, "Effect of Instruction on Superstitious Beliefs," *Journal of Educational Research,* XXXI (March, 1938), 481–96; George Wessell, "Measuring the Contribution of Ninth-Grade General Science Courses to the Development of Scientific Attitudes," *Science Education,* XXV (November, 1941), 336–39.

evidence,[22] on the whole, is convincing that direct teaching for scientific attitude and of scientific method is more effective than instruction not focused directly upon these outcomes.[23]

EXPERIENCES CONDUCIVE TO THE LEARNING OF SCIENTIFIC ATTITUDES AND METHODS

The principles of learning which are to be observed in teaching directly for the attitudes and methods of science are the same as those applicable for any other educational objective. The experiences should be psychologically sound, with due cognizance given to student aims and needs. There should be student activity—such as would be in agreement with the types of learning involved in the student's objective. There is also need for wise direction for the student's endeavors. The teacher's own attitudes and methods are certain to be influential in such learning situations.

With reference to the acquisition of scientific methods and attitudes, it seems obvious that if students are to develop these abilities they must have practice in them. That is, situations should be designed to allow students to select worth-while problems and attempt to solve them. They should have experiences in collecting data, making guesses, devising experiments, and checking for accuracy while cultivating methods and attitudes conducive to effective learning in the field of science. Suggestions for analyzing and carrying out such operations have been made by Goldstein.[24]

Evaluation of Individual Aptitude in Science

THE DISTINCTION BETWEEN APTITUDE AND ACHIEVEMENT

The major distinction between aptitude and achievement is temporal: achievement refers to present or past accomplishments; aptitude relates to the possibility of future accomplishment. Achievements depend, in part, on prior aptitudes, and aptitude as a predictor

22. J. Wesley Eberhard and George W. Hunter, "The Scientific Attitude as Related to the Teaching of General Science," *Science Education*, XXIV (October, 1940), 275–81; James S. Perlman, "An Historical versus Contemporary Problem Use of the College Physical Science Laboratory for General Education," *Journal of Experimental Education*, XXI (March, 1953), 251–57.

23. Curtis, *op. cit.*

24. Philip Goldstein, *How To Do an Experiment*. New York: Harcourt Brace & Co., 1957.

of future achievement involves present and past accomplishment. Despite this ambiguity in expression, the terms here employed have some utility.

For persons untrained in a field, aptitude, either on logical or empirical grounds, may be found to be a complex of intelligence, reading ability, reasoning skills, interests, attitudes, and motor skills. At a more advanced level, such as for graduate work in science, achievement in undergraduate courses as determined by grades or tests will become an additional and significant component of aptitude. As these last two sentences imply, attempts to assess aptitude may create a wide array of relevant concepts such as knowledge, intelligence, personality, physique, and motor skill. Achievement, on the other hand, refers to tangible accomplishments in the field which in science might be exemplified by knowledge, laboratory skills, or completed research.

THE COMPONENTS OF SCIENTIFIC APTITUDE

The phrase "scientific aptitude" appears to have clear meaning until the attempt is made to define it. The simple phrase, then, involves a complex of interacting hereditary and environmental determiners which produce the predispositions or abilities spoken of as scientific aptitude. All studies indicate that high intelligence is very significant for success in any task dependent on the manipulation of symbols and the formulation of concepts and conceptual schemes (theories). High intelligence is essential to scientific achievement. Additional mental factors that appear to be associated with success in science are intellectual curiosity, ability to apply knowledge to new situations, retentive memory, and insight into abstractions.[25] These attributes are similar to those found in generally gifted individuals. Such factors as physical development, social and emotional maturity, moral character, interests, attitudes, and skills may also be facets of scientific aptitude.

Relation of Scientific Aptitude to Attitudes, Critical Thinking, and Other Qualities. The use of the phrase *scientific aptitude* implies that persons possessing certain characteristics can be identified and that such individuals can succeed in scientific endeavor. Thus, the

25. *Education for the Talented in Mathematics and Science.* U. S. Department of Health, Education, and Welfare, Bulletin 1952, No. 15. Washington: Government Printing Office, 1953.

characteristics of able scientists suggest some of the criteria for locating individuals with aptitude for science. These characteristics include mental acuity, creative abilities, capacity for critical thinking, ability to see relationships, suspended judgment, and open-mindedness. Factors that predispose to such traits constitute at least a part of scientific aptitude.

Patterns of Ability and Predictions of Success. Brandwein postulates three factors:

1. A genetic factor for verbal and mathematical potential.
2. A predisposing factor consisting of persistence and "questing."
3. An activating factor involving opportunities and a special kind of teaching.[26]

MacCurdy[27] reported detailed descriptions of the superior science student with respect to personality, attitudes and opinions, activities, interests, family history, associates, science teacher, and decision to be a scientist. Some of the traits cited were: leadership, self-control and self-discipline, curiosity, persistence, antisocial attitudes, excellent performance in scholarly activities, and manifestation of scientific interest. He concluded that capacity, interest, and freedom are qualities that are paramount in the life of the superior science student. Neivert[28] concluded that high intelligence, opportunity for development, and personal attributes were the three factors necessary for high science potential and for determining the selection of science as a career. She listed the science teacher as the most influential single factor in the school environment for the development of the potential scientist. By releasing him from routine requirements and replacing these by more challenging opportunities, and by supplying or suggesting sources of materials and equipment, the science teacher may succeed in stimulating the able student.

Patterns of ability in science seem to follow the general patterns that have been cited for the gifted child. Such a child tends to be taller, healthier, and stronger than other children and relatively free

26. Paul F. Brandwein, *The Gifted Student as Future Scientist.* New York: Harcourt, Brace & Co., 1955.

27. Robert Douglass MacCurdy, "Characteristics of Superior Science Students and Their Own Subgroups," *Science Education,* XL (February, 1956), 3 ff.

28. Sylvia S. Neivert, "Identification of Students with Science Potential." Unpublished Doctor's dissertation, Teachers College, Columbia University, 1955.

from nervous disorders.[29] The gifted pupil also tends to show superiority in desirable personal traits, to possess superior self-criticism, to receive more opportunities as a leader, and to stand above the average in moral qualities.[30]

Success in college is a prerequisite to success in science in the present day. There have been many studies of the factors involved in success in college. Burnett says that studies of student success in college can best be predicted on the basis of intelligence and reading comprehension, together with high-school achievement indicative of self-sufficiency that might be epitomized as self-responsibility and study ability. He states further that achievement scores in specific subjects provide the lowest predictive correlations.[31]

METHODS OF TESTING FOR SCIENTIFIC APTITUDE

Review of Various Tests and Factors Measured. Scientific aptitude, defined as potentiality for future accomplishment in science without regard to past training and achievement in this field, appears to be dependent upon a variety of factors. These factors are not necessarily unique to potential success in science but may be equally functional in determining success in other areas. Few attempts, therefore, have been made to develop tests of aptitude for the science area alone. The *Stanford Scientific Aptitude Test*, first published in 1929, does, however, represent such an attempt. Ingenious though it is, this test points up some of the difficulties that can beset an individual who undertakes to develop an instrument to measure scientific aptitude. Each of the fourteen components established by the author of the Stanford test is so sparsely represented that reliability indices for the individual parts are unsatisfactory. Crawford obtained a reliability of .60 for the test as a whole when he administered it to entering Freshmen at Yale University. He also reported a correlation of only .30 between scores earned on this test

29. Marian Scheifele, *The Gifted Child in the Regular Classroom.* New York: Bureau of Publications, Columbia University, 1953.

30. *Education for the Talented in Mathematics and Science, op. cit.*

31. R. Will Burnett, *Teaching Science in the Secondary School.* New York: Rinehart & Co., 1957.

by entering students and their first-year grades or marks in science and pre-engineering courses.[32]

More recent attempts to measure aptitude have taken the form of aptitude test batteries. The *Differential Aptitude Tests* were developed by Bennett, Seashore, and Wesman of the Psychological Corporation and published by that company in 1947. The battery consists of seven separate tests: verbal reasoning, numerical ability, abstract reasoning, space relations, mechanical reasoning, clerical speed and accuracy, and language usage (consisting of two parts—spelling and sentences). Reliability coefficients obtained for these tests by a split half technique range from .86 to .93. In answer to the question of primary concern, namely, "How well do these tests serve as predictors of success in science?" the authors have provided the median correlation of scores on the *Differential Aptitude Test* with school grades earned in science courses in 28 different secondary schools as follows: verbal reasoning, .55; numerical ability, .51; abstract reasoning, .44; space relations, .36; mechanical reasoning, .38; clerical speed and accuracy, .26; spelling, .36; and sentences, .48. Thus it appears that success in science shows highest correlation with verbal reasoning, numerical ability, and certain aspects of language usage. Contrary to popular belief, mechanical reasoning and space relations do not show very high correlations with science achievement.

The *Guilford-Zimmerman Aptitude Survey*, published in 1950 by the Sheridan Supply Company, Beverley Hills, California, was designed for use in Grades IX to XVI and with adults. It consists of seven parts or subtests: verbal comprehension, general reasoning, numerical operations, perceptual speed, spatial orientation, spatial visualization, and mechanical knowledge. Correlation coefficients between part scores and grades earned in college science courses are reported by the test authors as follows: verbal comprehension, .42; general reasoning, .36; perceptual speed, .24; and spatial visualization, .25. While these tests reflect a high degree of skilful and ingenious craftsmanship in their construction, the accompanying validation data appear to be rather meager.

32. A. B. Crawford, Critical Review (No. 1676) of *Stanford Scientific Aptitude Test*, in *Nineteen-Forty Mental Measurements Yearbook*. Edited by Oscar K. Buros. Highland Park, New Jersey: Gryphon Press, 1941.

A Test of Aspects of Scientific Thinking,[33] an aptitude test which does not presuppose mastery of science content or technical language, can be regarded as an aptitude test designed to serve as a predictor of success in science. The scores earned on this test by entering students at Michigan State University as a part of their orientation test battery were found to correlate .64 for men and .64 for women with grades earned in the Freshman course in natural science. Two forms of this test, each consisting of 75 items, represent the ultimate refinement from an original stock of approximately 1,000 items that were written, tested, analyzed, revised, and retested in a series of try-outs. This test is suitable for late high-school and beginning college level.

Achievement as an Index of Aptitude. All of the afore-mentioned tests attempt to measure aptitude primarily as potentiality for future accomplishment in science. They do not involve the student in learned science content or technical vocabulary as a prerequisite for being able to understand what is to be done with the items in the tests. Another concept of aptitude for science seeks to relate past achievement *in science* with future accomplishment in a given area. The widely used *Science Aptitude Examination*, which is prepared annually for the Science Talent Search conducted by Science Clubs of America for the purpose of identifying high-school Seniors who might qualify for Westinghouse Science Scholarships, reflects this concept of science aptitude. This is a science achievement test which involves the student in exceedingly detailed and precise science content and technical science vocabulary. It also serves as an indirect measure of interest in science by confronting the student with aspects of science that only the most highly motivated would have delved into beyond the course that is typically taught in the classroom. The following are examples of items, from Part A of the 1957 edition of this examination, which embody concepts not likely to fall within the learning experiences of typical high-school science students:

24. Which of the following electronic devices must be operated at a temperature of about 4 degrees Kelvin?
    1. cryotron

33. Mary Alice Burmester, "The Construction and Validation of a Test To Measure Some of the Inductive Aspects of Scientific Thinking," *Science Education*, XXXVII (March, 1953), 131–40.

2. klysotron
3. magnetron
4. pliotron

39. To scale off, as the skin or mucous membrane of their living cells in certain diseases, is called
    1. decannulation
    2. decimation
    3. despumation
    4. desquamation

40. Which of the following is *not* considered a carcinogen?
    1. butter yellow
    2. methylchelanthrene
    3. trypan blue
    4. 3, 4-benzprene

Part B of the examination contains a series of ingenious problem situations which appear to be more useful than the items in Part A of this examination for the purpose of identifying ability to do scientific thinking and reasoning from data. Part C consists of science-content items from the traditional biological and physical science areas. The pattern of answers to the exercises in this part of the test would tend to reveal how well the student learned, understood, and remembered the subject matter from his high-school science courses.

Thus it appears from the foregoing paragraphs that aptitude for learning science can most readily be identified either by using subtest scores from the verbal- and numerical-ability sections of a general aptitude test battery, such as the *Differential Aptitude Tests*, or by using the scores from an instrument such as *A Test of Aspects of Scientific Thinking*, which involves the student in experimental and interpretative skills of the kind that are required in science. Both of these tests place major emphasis upon interpretative ability and the use of reflective thinking in solving problem situations which are presented in nontechnical language. These tests measure aptitude for learning science rather than achievement in science. By contrast, outstanding student performance on *The Science Aptitude Examination*, which is used in the science talent search, tends to reveal past activity in science that has gone far beyond the usual classroom requirements. A high score is usually indicative of intense interest in science on the part of the student—interest which has carried the student into the technical aspects of one or more specialized branches of science.

The Possibility of Early Identification of Scientific Talent. Participants in a conference on Education for the Talented in Mathematics and Science, held in Washington, D.C.,[34] expressed the belief that, in addition to evidence from formal testing at the secondary-school level, informal methods could be used by the classroom teacher, beginning in the elementary grades, to identify the student with potentiality for science. In the typical science class, the student who completes routine assignments to near perfection receives a relatively high mark for his efforts. Such performances alone should not be interpreted to mean that this student possesses high potentiality for science. Evidences of creativity and of special interests are more fruitful in identifying genuine science talent. The following characteristics, which some students possess, may serve as indices of potentiality for science:

1. Extraordinary memory, not as a definitive substitute for reasoning but as a concomitant of it. Extraordinary memory seems to indicate a capacity for superior learning, particularly learning that entails ability to discern relationships among many sequences of entities.
2. Intellectual curiosity, which is often indicated by persistence in asking questions and an eagerness to investigate peripheral content of a kind that usually challenges only those who are intellectually mature.
3. Ability to do abstract thinking, which may be revealed by unusual insight into probable discrepancies and by skill in formulating hypotheses from new data.
4. Ability to apply knowledge to situations other than those taken up in class or described in the textbook. The student who selects formulas and principles or invents new formulas and applies them to new situations is exhibiting such ability. This kind of ability is found in superior students.
5. Persistence in worth-while behavior, which is a characteristic common to leaders in science. Being motivated by the prospect of ultimate success to repeat again and again an experiment that has failed, introducing with each repetition some new refinement in technique, is characteristic of the individual who is likely to succeed in scientific research. A scientist does not give up easily, but neither does his perseverance degenerate to aimless plodding.
6. Insight into abstractions, which is observed to an extraordinary degree in the scientist and mathematician. Many talented students always seem to see the answer before the problem is completely stated. Teachers have reported cases of outstanding students who not only saw the

34. *Education for the Talented in Science and Mathematics, op. cit.*

answer immediately but also formulated almost spontaneously a new problem on a much higher level of abstraction.

7. Knowledge in advanced areas. Gifted students with high potentiality for science often show evidence of sound knowledge in advanced areas which they have explored by themselves.

Some of the foregoing characteristics are not revealed by formal tests given to an entire class but are more readily discernible in a few individuals in unstructured, informal situations that arise, often quite unexpectedly, in the classroom or on field trips. The teacher who has insight and sensitivity to such manifestations of unusual endowments can use these evidences wisely in directing and evaluating the progress of gifted students by maximizing opportunities for their intellectual development. Talent on the part of the student is necessary but not sufficient for success in science. Teachers should not only provide opportunities for the development of talent among their students but should also keep records of the occasions when talent was manifested and of the way in which students were challenged to utilize their emergent talents.

METHODS OF TESTING FOR SCIENTIFIC ACHIEVEMENT

In measuring achievement in science courses, the first question to be posed is, "What is to be achieved?" Every course is presumably taught for some purpose. For measurement of advancement toward the goals, the selected objectives must be defined. One of the problems which confronts every teacher of science, both in planning learning experiences for the student and in evaluating his progress, is the generality and broadness of the statement of recognized objectives. For example, consider the objective stated in the report of the President's Commission on Higher Education:[35] "to acquire and use the skills and habits involved in critical and constructive thinking." Such an objective, though philosophically satisfactory, is of little value as a guide to specific teaching practices or for the construction of test items. An analysis of this objective might indicate that "the ability to think scientifically" is one of several somewhat specific objectives suggested by the very general one. But even this objective does not suggest examination items. What are some of the

35. *Higher Education for American Democracy*. Vol. I, *Establishing the Goals*. Report of the President's Commission on Higher Education. Washington: Government Printing Office, 1947.

components of the ability to think scientifically? The ability to recognize problems is one aspect; the ability to plan experiments to test hypotheses is another; the ability to interpret data, still another. These objectives are more specific yet do not specify measurable behaviors. Further analysis of the objective, the ability to plan experiments to test hypotheses, leads to such behaviors as the ability to criticize faulty experimental procedures. This objective does suggest essay-type test items but leaves much to be desired if objective test items are to be constructed on the basis of the objective. Further analysis of this objective leads to such statements as the ability to recognize a lack of sufficient data, and these behavioral outcomes suggest the form of a key for a specific item:

Key: 1. The conclusion is warranted.
2. The conclusion is not warranted because the experiment lacked a control.
3. The conclusion is not warranted because the control was faulty.
4. The conclusion is not warranted because the data were insufficient.

This key can then be followed by brief statements of experiments and the conclusions drawn from them. For example:

PROBLEM: A person wanted to know what caused a certain disease. He examined 1,000 patients with the disease. All had certain bacteria (Bacteria A) in the digestive tract.
He concluded that Bacteria A was the cause of the disease.

Thus, detailed analysis of objectives leads to more and more specific behaviors, which in turn provide clues for teaching procedures and for test items to evaluate achievement toward these goals.

Many studies have been made of stated objectives for science teaching, and several classifications of these objectives have been suggested. One of the most widely used is the one presented in *Science Education in American Schools* (Forty-sixth Yearbook of the National Society for the Study of Education, Part I). Certain criteria for the formulation of objectives were set up by the yearbook committee. The recommendations were that the objective should be practicable for the classroom teacher, psychologically sound, possible of attainment, universal in a democratic society, and should indicate the relationship of classroom activity to the desired changes in human behavior. On the basis of these criteria, the com-

mittee suggested eight categories of objectives. A modified grouping of objectives is presented in chapter ii of the present volume.

A second classification, the *Taxonomy of Educational Objectives*,[36] is very general in scope in that it is designed for all subject-matter areas but is very specific in terms of objectives stated. It was especially designed as a means of improving the exchange of ideas and materials among test constructors. The criteria accepted by the committee formulating these objectives were:

1. The objectives should be defined in terms of desirable behaviors.
2. Each major category should be susceptible of division.
3. Each category should be psychologically valid.
4. It should not favor any particular method or philosophy of instruction.

On the basis of these criteria, the following objectives were selected: (*a*) knowledge, (*b*) comprehension, (*c*) application, (*d*) analysis, (*e*) synthesis, and (*f*) evaluation. Each of these objectives was subdivided, the subdivisions of each area progressing from simple to more complex objectives. Each of the classes and subclasses was verbally defined. The final subclass in each category is followed by specific behavioral objectives, such as "ability to define technical terms by giving their attributes, properties, or relations." Finally, behaviors were made more explicit by the inclusion of test items which call forth these specific abilities.

There are a number of standardized tests for the various grade levels and subject-matter areas of science. The criticism leveled at most of them is that they measure primarily knowledge objectives. There are, however, an increasing number of tests which purport to measure other important objectives of science. Reviews in the *Mental Measurement Yearbook*[37] give evidence that there are now standardized tests in most areas which do more than test for subject-matter objectives.

One contribution to the field of measurement is a compendium of approximately 13,000 test items in the areas of both the physical and the biological sciences.[38] From it a teacher can construct unit and/or

36. *Taxonomy of Educational Objectives*. Edited by Benjamin S. Bloom. New York: Longmans, Green & Co., 1954.

37. *Mental Measurements Yearbook*. Edited by Oscar K. Buros. Highland Park, New Jersey: Gryphon Press, 1953.

38. *Questions and Problems in Science*. Edited by Paul L. Dressel and Clarence H. Nelson. Princeton, New Jersey: Educational Testing Service, 1956.

term-end examinations. The items are classified on a double classification system of content and objectives, to aid in the preparation of well-balanced examinations. The system of classification used for the designating of objectives was the one presented in the *Taxonomy of Educational Objectives.*

Since one of the axioms of measurement is that objectives not tested in examinations are not real objectives to students, it behooves every teacher to include items in examinations which measure accomplishment of all of the real objectives of a course. Since items which measure knowledge objectives are usually easiest to construct, there is a tendency to test for subject-matter objectives at the expense of other objectives. To remedy this situation, a thorough investigation of all of one's course objectives should be undertaken, and an analysis made of each and all of the desired behaviors related to each objective recorded. When this task is completed, a double classification system should be used to aid in the preparation of the examination, thus insuring the inclusion of items to measure each type of objective which is a desired outcome of the course. Objectives involving scientific methods and attitudes will then become explicit goals of science instruction, both to teachers and to their students.

OBSTACLES TO MEASURING LEARNING IN SCIENCE

The general impression obtained from review of the literature on science education is that science educators give infrequent attention to the problem of evaluation of instruction. This may not reflect lack of interest so much as it indicates the complexity of the problem and the inability to subject it to rigorous and illuminating study. There are difficulties involved in measuring learning in science that make the task formidable not only for the classroom teacher but also for those who are in a position to study and develop evaluation programs.

One difficulty is that school administrators, teachers, parents, pupils, and the general public fail to agree on the relative emphasis to be placed on various science objectives. Amid this confusion it is understandable that high-school science teachers have tended to lag in the development of thorough programs for evaluating science in-

struction for outcomes other than those most easily accomplished through ordinary paper-and-pencil tests.

A second obstacle to adequate evaluation stems from the popular American mass approach to education which assumes that all students with the proper effort can achieve the same goals. The result has been the development of science programs which serve no group of students especially well. The less-able student learns almost nothing. The superior student may learn little which he does not already know. And even the average student may only memorize content materials which are mechanically and unimaginatively geared to those who will ultimately engage in advanced scientific study. Current public pressure for more intensive scientific education for everyone may simply aggravate this situation.

A third difficulty lies in the inadequacy of the evaluative techniques available to classroom teachers. The preparation and validation of objective test questions is a time-consuming process. Direct observation, personal conferences, anecdotal records, systematic written reports, to mention only a few other suggested evaluation techniques, are even more time-consuming and often less reliable. Many suggestions for evaluation contained in the literature are too vaguely described and too complex to interest the average high-school teacher.

Perhaps the greatest difficulty experienced by classroom teachers is a result of the inadequacies of their own knowledge of modern science. Often with a minimum of preparation in science, they are prevented by heavy and diversified teaching schedules from spending sufficient time to maintain and advance their knowledge of science. This problem is magnified by low salaries, which have driven many teachers to seek additional sources of income during after-school hours and summers. Teachers so preoccupied may have little recognition of the nature of science and little interest in evaluation at other than the level of factual knowledge.

A further difficulty arises from the proliferation of objectives. Each objective has been analyzed into many subobjectives. Although this has been a useful device, it may be time for the profession to identify as clearly as possible *two* or *three* objectives of special significance and urge each teacher to emphasize these objectives. As an example, the profession could decide that knowledge of facts and

principles basic to an understanding of certain limited topics should be considered essential in all high-school programs. The profession might also urge that at least 50 per cent of all instructional time be devoted to the development of thought processes as exemplified in scientific pursuits. Such a decision would free teachers to give more time to individual laboratory instruction, in which students would be encouraged to set up original experiments for testing hypotheses, observing phenomena, or interpreting data. Such changes in teaching procedure would lead to a more genuine evaluation of significant aspects of science teaching.

Assuming that some or all of the difficulties which have been noted can be mitigated by steps implicit in the very nature of the difficulty, it will still be necessary to do more than we have been doing to provide the teacher with materials and ideas which will assist in the evaluation process. Folios of test questions and problems similar to the one prepared by Dressel and Nelson[39] for use at the college level might well be designed for the secondary-school level. Such compilations of testing materials would assist teachers materially in constructing examinations consistent with their instructional objectives. They should, in addition, provide valuable models for teachers attempting to create their own test items.

It is important also to provide source material for methods of evaluation other than paper-and-pencil tests. Particularly needed are compilations of experiments and problems on which students can demonstrate their ability to apply knowledge of facts and principles. They must involve procedures which can be managed without great expenditure of time on the part of the teacher. Practical ideas for using students' self-motivated activities as means of evaluation should also be offered. Such activities as voluntary reading projects and all other evidences of science interests can constitute a valuable basis for determining the success of science instruction.

Proper control of institutional, state-wide, and national scholarship examinations could be a boon to the improvement of classroom evaluation. No teacher can be expected to ignore the public demand and competition for students' success on these tests of factual knowledge and reading ability. Since such poorly devised testing programs cannot easily be discarded, the only sensible alternative seems to be

39. *Questions and Problems in Science, op. cit.*

that the profession strongly encourage publishers to add other dimensions to their tests in order to bring them into line with instructional objectives which are generally accepted by the profession.

A final urgent suggestion for improving the evaluation of instruction in science education involves co-operative research. It is apparent from a review of research studies undertaken over the past ten years that science educators, working individually, find it most difficult to attack problems of sufficient scope or significance to have publication value. Many teachers who do not have time to undertake research projects on their own may still make important contributions to the work of a group studying a common problem. Particularly needed are studies using the experimental approach. Out of this type of research might come significant progress in the evaluation of science instruction during the next decade.

A Point of View about Learning Science

Science is not just an accumulation of facts; indeed, the "facts" of science today may not be facts tomorrow. Science is a composite of observations, facts, definitions, concepts, laws, principles, and theories. But perhaps more important are its components of attitudes and modes of reasoning which lead to the organizations and the applications thereof. Science is descriptive, analytical, and synthetic. It is both quantitative and verbal. No individual truly learns science who learns only the results of scientific activity; he must grasp the rules, logic, and procedure which characterize that activity. In a word, he must become, to a degree, scientific. No wonder, then, that no final statement can be made on the identification of scientific talent, or on the teaching and learning of science. Clearly, both testing and teaching must involve a wider range of objectives than has been the case in much of past practice. Clearly, too, as many of the studies reported in this chapter demonstrate, types of testing and teaching which are oriented to this broader conception of science can produce superior results by emphasizing such enriched learning experiences.

CHAPTER IV

Creativity and Personality in the Scientist

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Sociologists, psychologists, psychiatrists, anthropologists, natural scientists, science teachers, and educational administrators have pondered the question: What makes a scientist? The methods of study employed vary; refined statistical procedures, biographical study, psychometric approaches, and logical analyses of observations of scientists at work have all been used. One valuable analysis[1] of work in vocational development theory as it relates to scientific careers lists a bibliography of 229 papers.

Our concern is with the factors related to success in science, particularly as these factors relate to the aims and activities of the school. We propose to develop this area under four heads: (*a*) the nature of creativity, (*b*) factors related to success in science, (*c*) the social atmosphere and personality as a factor in the choice of scientific careers, and (*d*) a picture of the individual "successful" in science.

Nature of Creativity

Many discussions of creativity and the creative process would have been clarified if a distinction had been made between the process itself and the product or the results of the process. The process itself, that is, *what goes on within the individual,* is not directly related to any value which may be ascribed to the product. It is not related to the absolute uniqueness of the product or even to its adequacy. There are artistic productions and scientific theories

1. Donald E. Super and Paul B. Bachrach, *Scientific Careers and Vocational Development Theory.* New York: Bureau of Publications, Teachers College, Columbia University, 1957.

which were rejected when they were first offered, only to be acclaimed by later generations; there are others which were acclaimed and have since been rejected; but the process within the artist or scientist was as creative in one instance as in the other. Similarly, the discoveries a child makes may be true creations, even though other persons have made them before him. There have been many creative solutions to problems which did not prove to be solutions at all, but the process by which they were derived was no different from the one which gave results that could stand the test of verification.

What is this process and how has it been studied?

Creative thinking is not very clearly distinguished from thinking that is termed problem-solving or logical thinking or reasoning. It should be emphasized that none of these can be considered taxonomic categories; rather, they are convenient but artificial subdivisions of an ongoing activity set up to make it possible to study this activity in manageable units. Unfortunately, once such categories get into general use they tend to become reified and treated as substantive units. It seems, however, to be the consensus that we may appropriately regard thinking as creative when a number of discrete units become organized into a new (to the organizer) and meaningful pattern or formulation. It is usually added that this formulation must also be new and meaningful to some society at some time, although as has been noted, this is irrelevant to the process itself.

The perception of this pattern by the creator is what is termed *insight*, and it is supposed always to be sudden in its emergence, but this need not in fact be the case. (Some definitions state that without this sudden insight there is no true creation, but this seems an unnecessary and meaningless restriction.) The psychological activities preceding the emergence of this new formulation are the least understood part of the whole process, since to a considerable extent they are not fully conscious. Those activities that customarily follow, before the creator is satisfied with his creation, are usually rather fully conscious and, in the scientific field, consist largely of testing out the new formulation to see if it works.

It has become increasingly clear that the process involved in creative thinking, particularly in the early stages and whether in science, the arts, or in any other field, is not one which is solely an exercise of the intellect and coldly rational. It requires a focusing of

the total person and immersion in the problem, yet it is scarcely at all under conscious control. Thurstone remarks: "Creative talents [are] determined in a descriptive way by the rapport that the actor has with his own preconscious thinking."[2] Too intensive a concentration upon the problem seems to prevent that recourse to the depths of the person that is required. It frequently happens that the resolution, or insight, appears in consciousness during a period of dispersed attention, but conscious efforts to disperse attention to permit or facilitate such resolutions have not been successful.

Under these circumstances, it is clear that attempts to study the process itself have had to center largely upon retrospective inquiry, upon attempts to find out after the act what was going on during the action. Since so much of the process is not conscious, this has been difficult. Such attempts have more often been made in connection with artistic rather than scientific productions. Yet more direct studies are being instituted which may give us some leads to individual management and release of conscious control.

After completing a study of originality in relation to intellect, Barron offers the following explanation:

> The effectively original person may be characterized above all by an ability to regress very far *for the moment* while being able quite rapidly to return to a high degree of rationality, bringing with him the fruits of his regression to primitive and fantastic modes of thought (a variant of the phenomenon termed "regression is the service of the ego" by Lowenstein and Kris). Perhaps when the cortex is most efficient, or intelligence greatest, the ego realizes that it *can afford to allow* regression—because it can correct itself. A basic confidence in one's ability to discern reality accurately would thus facilitate the use of the powers of imagination.[3]

Some advances in understanding of creativity have been made by rather roundabout approaches. One can study the differences between those cultures which may be related to richness of creative productions in one or more fields. One can study the circumstances under which the same individuals are more or less creatively productive. Or one can study aspects of creativity in terms of intellectual or personality variables in persons of varying degrees of demonstrated

2. L. L. Thurstone, *Creative Talent.* Chicago: University of Chicago, Psychometric Laboratory, No. 61, December 1950.

3. Frank Barron, "Originality in Relation to Personality and Intellect," *Journal of Personality*, XXII (1957), 730–42.

creativity. Finally, there are factorial studies of populations not specifically identified as creative but covering various abilities believed to be important in creative thinking.

That the nature and number of creative productions vary from culture to culture and in the same culture at different times has been amply documented by Kroeber.[4] The concomitants of this variation are not sufficiently known to warrant a general statement, but it is clear that the total culture pattern is a highly significant force in the creative life of the individual.

Some studies are now in progress in industrial and other research laboratories designed to evaluate the conditions under which their research personnel are most productive. Since, in almost all of these instances, there is some direction of the research worker's efforts, the situation differs from that of the more academic research worker who is free to follow his own bent.[5]

In questioning individual workers as to the circumstances under which they produce their best work, a considerable number of differences are found. Some, for example, work best under moderate pressure, others under fairly heavy pressure, such as deadlines. Some work in spurts, others steadily. In general, it is true that the most effective work is done under conditions of minimal impingement of other interests, but how much other matters are permitted to impinge and how they can be resisted without too much drain on energy is highly variable. There is some reason to think that too easy availability of equipment and assistance may reduce motivation, but this is likely to cause more interference with young research workers than with seasoned ones. One problem that recurs with older research workers is that of the number of administrative or professional organizational jobs that come their way, which need to be done but which are distracting from research.

Is there anything in the background, early history, training, or intellectual or personality characteristics of the highly creative individual which distinguishes him from less creative persons?

4. Alfred Kroeber, "Configurations of Culture Growth." University of California.

5. Some interesting suggestions for ways of teaching in school so as to encourge creativity are given by Robert C. Wilson in chapter vi of the Fifty-seventh Yearbook of the National Society for the Study of Education, Part II, *Education for the Gifted* (Chicago: Distributed by University of Chicago Press, 1958).

For our present purpose our concern is centered upon scientists. However, the consensus is that the creative *process* is the same regardless of the subject matter on which it works. But the evidence points to some patterning of concomitants in accordance with the field of work.

It seems to be generally agreed that there is no single characteristic, possessed by some persons and not by others, having which the persons can be creative and lacking which they cannot be creative. Except for the possible occurence of pathology, every human has some degree of creative talent.

There seems to be some correlation between intelligence and creative production, at least in those instances in which the products are recognized socially. It is entirely possible that the correlation is actually between intelligence and the social usefulness or acceptance of the product rather than with the creativeness of the producer—the actually creative products of stupid people may just go unrecognized as such. In any case, in science, the creative person needs above-average intellectual capacities, in general, and probably needs also to be above average in certain special factors, although the relevance of individual factors will vary with the field of work. For example, most research scientists need above-average ability in numerical and spatial factors, although this seems not to be true of some social scientists.

Thurstone suggests that these factors may prove of special importance: first and second closure factors, perceptual speed, visual memory, memory for paired associates, incidental memory, and the inductive factor.[6]

Guilford and his associates have been engaged in extensive analyses of intellectual factors and in construction of an organized system of factors. At the present time they conceive of intellectual factors as falling into five categories of primary abilities, each of which contains diverse factors, grouped as figural, structural, and conceptual. They have reported that many of these new factors bear significant relationships to criteria of success in the steps of learning sciences and mathematics and in practical scientific and technological work. (Their subjects were students in mathematics, physics, and

6. L. L. Thurstone, *Examiner Manual for the Thurstone Temperament Schedule*, April 1953 (second edition).

engineering; aircraft engineers; and operations analysts.) It appeared that the discovery factors and the divergent-thinking factors are most important in creative scientific activity. Two principles were stated:

1. Scientific aptitude, including ability to do creative work in science is a many-sided phenomenon, involving many different abilities, depending upon the science and the particular steps within the science.
2. Most of the differences in what scientists are able to do can be accounted for in terms of the intellectual factors, some of which contribute more directly and some less directly to successful creative performance.[7]

In a later investigation (1957) Guilford and his associates reported very little relationship between traits of temperament and interest (such as neurotic tendency, need for freedom, need for variety, tolerance of ambiguity) and performance in tests of creative thinking, including the factors of word fluency, associational fluency, ideational fluency, expressional fluency, originality, spontaneous flexibility, and adaptive flexibility. His subjects were Coast Guard, Naval Air and Air Force cadets. These results are contrary to those reported by others, but Guilford and associates add:

> It is possible that *within* individuals we should find higher correlations between interests and aptitudes. It is also quite possible that we should find higher correlations between *composites* of interest scores and *composites* of aptitude scores, where each composite represents several factors in an area that seems logically more coherent for the average person. But within populations [of students] we may conclude that except for the special relations of the flexibility factors to perseveration and persistence, none of the creative-thinking activities appears to be even substantially accounted for in terms of temperamental and motivational traits, under the usual testing conditions. In everyday life, variations in motivation and temperament might have much more influence, having much greater freedom to operate upon performance.[8]

This last comment is given particular cogency by studies which have used successful scientists as subjects and which have indicated

7. J. P. Guilford, *The Relation of Intellectual Factors to Creative Thinking in Science*, pp. 69–95. University of Utah Research Conference on the Identification of Creative Scientific Talent, 1955.

8. J. P. Guilford, P. R. Christensen, J. W. Frick, and P. R. Merrifield, *The Relations of Creative Thinking Aptitudes to Nonaptitude Personality Traits.* Reports from the Psychology Laboratory, University of Southern California, No. 20, December 1957.

that there are differences in personality traits associated with research competence and with special fields of work. Other writers have pointed out certain items which occur with more than expected frequency in the backgrounds of such scientists.[9]

Cattell and Drevdahl have, by means of their 16 P.F. test, studied the personality profiles of 96 biologists, 91 physicists, and 107 psychologists, chosen by special committees as eminent in research or in teaching or administration. The scientists as a whole differed from the general population in the personality factors called general intelligence, ego strength or stability, dominance, desurgency, lack of group super-ego standards, adventurousness, sensitive emotionality, lack of paranoid tendencies, lack of free-floating anxiety, and compulsive super-ego (will control). Except for administrators, they were significantly higher in radicalism and self-sufficiency. They also reported differences between the different scientific groups and between researchers and the other groups.

It is easy to see that the schizothymic preoccupation with things and ideas, rather than people, the self-sufficiency which favours creativity and independence of mind; the dominance which gives satisfaction in mastery of nature for its own sake; and the emotional instability which permits radical restructuring and creativity, would all be vital to the best kind of basic research performance—although perhaps unpleasant in an administrator and inapt in a business man. The remaining factors of Bohemian unconcern and radicalism may perhaps best be regarded as condition and consequence of continued adjustment to the researchers' comparative earnings.[10]

Roe made intensive individual studies of 64 eminent research scientists (in biology, in physical science, and in psychology and anthropology) and Group Rorschach studies of 382 faculty members in these same sciences. She also found that certain reaction patterns appeared with greater frequency in some groups than in others, and

9. R. B. Cattell and J. E. Drevdahl, "A Comparison of the Personality Profile (16 P. F.) of Eminent Researchers with that of Eminent Teachers and Administrators, and of General Population," *British Journal of Psychology*, XLVI (1955), 248–61; Ann Roe, *The Making of a Scientist* (New York: Dodd, Mead & Co., 1953); S. S. Visher, "Environmental Backgrounds of Leading American Scientists," *American Sociological Review*, XIII (1948), 65–72; and R. B. Knapp and H. B. Goodrich, *Origins of American Scientists* (Chicago: University of Chicago Press, 1952).

10. Cattell and Drevdahl, *op. cit.*

results of other workers have been similar.[11] She further found differences in characteristic imagery use associated with the field of science.

As to other variables, it appears that research science is characteristically a middle-class activity; that those who go into biological and physical sciences and engineering early show less interest in personal and social associations and more in things and ideas; that in these groups, psychosocial development is likely to be retarded. Further, it is characteristic of the research scientist that he has always had an intense curiosity, a persistence in following his own interests, a general disinterest in conformity to many cultural stereotypes, and a self-starting willingness to work long hours over a long period of time.

We may well close with a review of Rogers' comments on the inner conditions which permit constructive creativity. He sees these as:

1. Openness to experience, i.e., openness to awareness of what exists at the moment
2. An internal locus of evaluation
3. The ability to toy with elements and concepts

And he believes that the following external conditions foster creativity:

1. Psychological safety, which is established when the individual is accepted as of unconditional worth, is provided with a climate in which external evaluation is absent, and receives emphatic understanding
2. Psychological freedom, i.e., complete freedom of symbolic expression[12]

Factors Related to Success in Science and Scientific Careers

This section deals with a number of intellectual and personality factors which are characteristic of individuals with high-level ability in science. These factors have been drawn from recent studies of eminent scientists and of high-school and college students who ma-

11. Roe, *op. cit.;* Morris Stein, "Creativity and Culture," *Journal of Psychology, XXXVI* (1953), 311–23; D. W. Taylor, *Research on Problem-solving and Creative Thinking* (Stanford, California: Stanford University Press (1956); and L. M. Terman, *Scientists and Non-Scientists in a Group of 800 Men.* Psychology Monograph, 1954, LXVIII, No. 7.

12. Carl Rogers, "Toward a Theory of Creativity," *ETC: Review of General Semantics,* XI (Summer, 1954), 249–60.

jored in science. Since the factors under discussion are not exclusively an endowment of science majors and scientists, they are more valuable for group evaluation than for individual prediction.

INTELLECTUAL FACTORS

Investigators are generally agreed that very superior intellectual endowment is a necessary prerequisite for high-level achievement in science and mathematics.

Brandwein studied a group of high-level achievers in high-school science and mathematics. His conclusions to the effect that certain intellectual characteristics appear to be related to the group's achievement were reported as follows:

> Assuming opportunities for development in science (the Activating Factor), students with a base I.Q. of 135 (Henmon-Nelson), a reading score (Nelson-Denny) of 15 in the ninth year, an arithmetic score of 12 plus in the ninth year (Arithmetic Judgment Test, New York City), are at the base level of the Genetic Factor postulated here as being a factor basic to high level contribution in science. It seems also to be essentially true that youngsters who place at the 90th percentile and above in the Tests of Primary Mental Abilities, specifically those titled Verbal-Meaning, Reasoning, and Number (developed by Science Research Associates, Chicago), or the Differential Aptitude Tests, specifically those titled Verbal Reasoning, Numerical Ability, and Abstract Reasoning (developed by the Psychological Corporation, New York), are also at the base level of the Genetic Factor which is postulated here as necessary to high-level contribution in science.[13]

Stone, making use of the quantitative, linguistic, and total intelligence scales of the *American Council on Education Psychological Examination*, compared the mean scores of a group of fifty Brooklyn College students who had successfully completed a rather demanding physical-science and mathematics curriculum with those of a more normative population of 1,133 students of the same college. The study population's mean scores were very significantly superior (.01 level of confidence) to those of the larger group on all three scales.[14]

13. P. F. Brandwein, *The Gifted Student as Future Scientist*, p. 48. New York: Harcourt, Brace & Co., 1955.

14. S. Stone, "The Contribution of Intelligence, Interests, Temperament and Certain Personality Variables to Academic Achievement in a Physical Science and Mathematics Curriculum," pp. vii+128. Doctors dissertation, New York University, 1957.

Roe administered a special Verbal-Spatial-Mathematical test prepared by the Educational Testing Service to 64 eminent scientists. She reported that their median scores on the Verbal, Spatial, and Mathematical tests were approximately equivalent to I.Q.'s of 166, 137, and 154, respectively.[15]

PERSONALITY FACTORS

There is a substantial agreement among investigators regarding the outstanding personality characteristics of individuals with high-level ability in science. Such strikingly similar descriptions of high-school and college science majors and of eminent scientists are found in the literature that one is forced to the conclusion that the scientific personality is fairly well developed by the ninth grade.

Brandwein described a group of high-school students with high-level ability in science in the following terms:

> In general, there was one personality characteristic which seemed almost obvious. The youngsters in the experimental 62 as compared with the "norm" of behavior at Forest Hills might be said to be more quiet, more reflective, more inward looking; in short they exhibited, in general, a tendency to introversion, as compared with the norm.[16]

Stone[17] employed a study population of 50 male college students who had successfully completed a physical science and mathematics curriculum. He compared the study population's mean scores on the *Kuder Preference Record—Vocational*, the *Thurstone Temperament Schedule*, and the *Minnesota Personality Scale* with those of the normative populations published by the authors of the tests.

Although the two groups did not differ significantly in the artistic, outdoor, and mechanical scales, the study population was superior in *computational interest* (work with numbers), *scientific interest* (work in problem-solving), *musical interest*, *literary interest*, and inferior to the study population in items of *persuasive interest* (to meet and deal with people, to promote projects, or to sell), and in the *social-service interest* (preference for helping people). The level of confidence at which the difference between the means of the two groups is significant was .01 for each of the six items. The fore-

15. Roe, *op. cit.* pp. 164–69.
16. Brandwein, *op. cit.*, p. 54.
17. Stone, *op cit.*, pp. 66–74.

going results are similar to those obtained by Kuder with a group of 54 chemists.[18]

The study population's superior performance on the scientific and computational scales is in accord with logical expectation. This investigator believes that the group's superior performance on the literary and musical scales and its inferior performance on the persuasive and social service scales may be related to a more basic preference for individualistic-intellectual rather than interpersonal-emotional activities.

The study population's mean scores differed significantly from those of the normative population on six of the seven scales of the *Thurstone Temperament Schedule* (the level of confidence is indicated in parenthesis). The study population was inferior in these: *active*, works and moves rapidly (.05); *vigorous*, uses large muscle groups and great expenditures of energy (.01); *impulsive*, quick decisions, enjoys competition (.01); *dominant*, thinks of himself as a leader, capable of taking initiative and responsibility (.05); *sociable*, enjoys the company of others, makes friends easily (.01). It was superior in this: *reflective*, likes meditative and reflective thinking, quiet, works alone, enjoys work that requires accuracy and fine detail (.01). The two groups did not differ significantly on the stable scale.

Roe described this orientation in the following manner:

> For reasons which are often obscure, the men who became physical and biological scientists early found special interests and special satisfactions away from personal relations. It was easier for them to become immersed in objects, in things, outside of the human realm.[19]

The development of an individualistic-intellectual orientation may serve as a compensation for deficiencies in other areas. This hypothesis is supported by Zim's work[20] with adolescents who displayed a marked interest in scientific activities and by Roe's work with eminent scientists. Zim wrote:

18. F. G. Kuder, *Profile Sheet for the Kuder Preference Record—Vocational, Form C* (First revision), February 1951; and *Examiner Manual for Kuder Preference Record—Vocational* (second revision), p. 14 (Chicago: Science Research Associates, 1951).

19. Roe, *op. cit.*, p. 236.

20. H. S. Zim, *Science Interests and Activities of Adolescents*. New York: Ethical Culture Schools, 1940.

Lack of affection at home, birth of a new brother or sister, splitting of the family or other internal problems may lead to compensatory efforts in a field of science interests. In many cases the adolescent attempts to compensate for some personal deficiency through activity in science. Such compensations may hinder normal growth for the student. There may be attempts to intellectualize some personal or emotional problem and to solve it by intellectual means [pp. 126–27].

Roe wrote:

Intellectual activities can become the predominant ones in the face of physical or social problems (given an environment in which they are valued by someone), and when they become so very early they may often be a defense against ineffectiveness or lack of satisfaction in other spheres.[21]

The study population's inferior performance on the *active* and *vigorous* scales is in harmony with the foregoing hypothesis. Originally, a real or imagined inferiority in these areas may have caused the group to seek its satisfactions through an individualistic-intellectual approach to life's problems.

The study population's mean scores were also significantly below those of the normative population on four of the five variables of the *Minnesota Personality Scale.*

The Study Population was Inferior in these: SOCIAL ADJUSTMENT. High Scores tend to be characteristic of the gregarious, socially mature individual in relations with other people. Low scores are characteristic of the socially inept or undersocialized individual (.05). FAMILY RELATIONS. High scores usually signify friendly and healthy parent-child relations. Low scores suggest conflicts or maladjustments in parent-child relations (.01). ECONOMIC CONSERVATISM. High scores indicate conservative economic attitudes. Low scores reveal a tendency toward liberal or radical points of view (.01). MORALE. High scores are indicative of belief in society's institutions and future possibilities. Low scores usually indicate cynicism or lack of hope in the future (.05).[22]

The two groups did not differ significantly on the Emotionality variable. The study population's significantly below-average performance on the economic conservatism scale is indicative of its liberal point of view on current economic and industrial problems. This finding was anticipated by Roe who judged that the political

21. Roe, *op. cit.*, p. 235.

22. J. G. Darely and W. J. McNamara, *Manual of Directions for the Minnesota Personality Scale*, p. 1. New York: Psychological Corp., 1951.

views of most of the scientists in her study population were "definitely liberal."[23]

The Social Atmosphere and Personality as a Factor in the Choice of Scientific Careers

In order to understand why a scientific career may be rejected by youngsters well qualified to pursue it, we may profitably consider how science as a pattern of life is likely to look from where they stand. We must try to understand how science is likely to be ranked, by youngsters, among the other choices possible to them, as a potential source of the kinds of satisfactions that man most wants. The work of Roe,[24] Cattell and Drevdahl,[25] Drevdahl,[26] and Guilford[27] has by now established a rather detailed picture of the personality of the American scientist and of the way in which scientists differ from successful persons in other fields. The pioneering work of Knapp and his associates,[28] and the more recent work of Holland[29] tell us something of value about where scientists come from, what kinds of colleges they choose for their training, and why they choose them. Havighurst and his collaborators have by now explored the role of the school in the American status system, with special emphasis on the values the school conveys and rewards, as has Riesman by more subjective means; while Becker,[30] in a series of exceptionally penetrating papers, has examined the ways in which that status system affects the career of the American public schoolteacher and through her, by making her the kind of person she is and selecting others to match, has set its mark upon American society.

23. Roe, *op. cit.*, p. 60.

24. Anne Roe, *The Psychology of Occupations*. New York: Wiley & Sons, 1956.

25. Cattell and Drevdahl, *op cit.*

26. J. E. Drevdahl, "An Exploratory Study of Creativity in Terms of its Relationship to Various Personality and Intellectual Factors." Doctor's dissertation, University of Nebraska, Lincoln, 1954.

27. Guilford, *op. cit.*

28. Robert H. Knapp and H. B. Goodrich, *Origins of American Scientists*. Chicago: University of Chicago Press, 1952.

29. John L. Holland, "Undergraduate Origins of American Scientists," *Science*, CXXVI (September 6, 1957), 433–37.

30. Howard S. Becker, "The Career of the Chicago Public Schoolteacher." *American Journal of Sociology*, LVII (March, 1952), 470–77.

Margaret Mead and Rhoda Metraux recently reported a pilot study of the image of the scientist among high-school students which sheds some light into the attitudes of youngsters toward scientists and the realm of science in general. Their study[31] involved 132 public high schools having a total enrolment of forty-eight thousand pupils who were qualified to participate in the Traveling High-School Science Library Program sponsored by the National Science Foundation and administered by the American Association for the Advancement of Science. When they found that this sample yielded nearly homogeneous results, they extended the study to include the pupils of thirteen additional high-schools, most of them being private schools, to see if the increase in pupils would make a difference; but they reported none.

In essence, Mead and Metraux found that a minority of students had a favorable image of the scientist, while a majority reported distinctly negative reactions. To quote Mead and Metraux's summary of statements indicating a favorable image of the scientist:

> He is a very intelligent man— a genius or almost a genius. He has long years of expensive training–in high school, college, or technical school, or perhaps even beyond–*during which* he studied very hard. He is interested in his work and takes it seriously. He is careful, patient, devoted, courageous, open-minded. He knows his subject. He records his experiments carefully, does not jump to conclusions, and stands up for his ideas even when attacked. He works for long hours in the laboratory, sometimes day and night, going without food and sleep. He is prepared to work for years without getting results and face the possibility of failure without discouragement; he will try again. He wants to know the answer. . . .

Mead and Metraux's summary of responses indicative of a negative image of the scientist follows:

> The scientist is a brain. He spends his days indoors, sitting in a laboratory, pouring things from one test tube into another. His work is uninteresting, dull, monotonous, tedious, time consuming, and, though he works for years, he may see no results or may fail, and he is likely to receive neither adequate recompense nor recognition. He may live in a cold-water flat; his laboratory may be dingy.
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> If he works by himself, he is alone and has heavy expenses. If he works for a big company, he has to do as he is told, and his discoveries must be turned over to the company and may not be used; he is just a cog in

31. Margaret Mead and Rhoda Metraux, "Image of the Scientist among High-School Students: A Pilot Study," *Science*, CXXVI (August 30, 1957), 348–90.

a machine. If he works for the government, he has to keep dangerous secrets; he is endangered by what he does and by constant surveillance and by continual investigations. If he loses touch with people, he may lose the public's confidence—as did Oppenheimer. If he works for money or self-glory he may take credit for the work of others—as some tried to do to Salk. He may even sell secrets to the enemy.

. . . .

He is a brain; he is so involved in his work that he doesn't know what is going on in the world. He has no other interests and neglects his body for his mind. He can only talk, eat, breathe, and sleep science.

He neglects his family—pays no attention to his wife, never plays with his children. He has no social life, no other intellectual interest, no hobbies or relaxations. He bores his wife, his children and their friends—for he has no friends of his own or knows only other scientists—with incessant talk that no one can understand; or else he pays no attention or has secrets he cannot share. He is never home. He is always reading a book. He brings home work and also bugs and creepy things. He is always running off to his laboratory. He may force his children to become scientists also.

"A scientist should not marry. No one wants to be such a scientist or to marry him."[32]

It should not be surprising to find that the scientist, in the image created by mass media of communication, should pose a threat to the average youngster. There seems general agreement that our environment is an anti-intellectual one and, after all, the student is in school only six hours per day for some 200 days per year. Possibly we should be more surprised at the high number of positive statements.

Mead and Metraux, in addition, state this in their study, and this significantly:

This is not a study of what proportion of high-school students are choosing, or will eventually choose, a scientific career. It is a study of the state of mind of the students, among whom the occasional future scientist must go to school and of the atmosphere within which the science teacher must teach.[33]

Although there is this kind of evidence indicating that the life of the scientist is generally regarded negatively by adolescents, there is other evidence pointing in the other direction. Thus, the report of the 1958 National Merit Scholarship program indicates that pure and applied science careers are regarded favorably by the ablest of

32. *Ibid.*, pp. 387–90. 33. *Ibid.*, p. 384.

high-school students. The 1958 Merit Scholars and finalists, 8,600 of them, were asked in what subject they would probably major in college. Of 5,916 boys, 29 per cent said they were going into engineering, 39 per cent into science (mainly physics) or mathematics, 9 per cent into the health professions (mainly medicine)—a total of 77 per cent indicating a desire to go into pure or applied science. Among the 2,693 girls, 2 per cent intended to go into engineering, 33 per cent into science or mathematics, and 11 per cent into the health professions (including nursing).

A study by the National Association of Science Writers[34] reported the images that high-school Seniors hold of scientists are as follows:

> Two predominant portraits of the scientist grew out of the questioning of 1,919 respondents in this survey. One was highly positive; the other negative. The favorable was far more widely held. Few people indeed painted a completely negative picture, rather blending in some good with any unfavorable comments. Neither picture showed the scientist as a person trained to do a full-time job of a certain sort, which probably would have been nearer the truth.
>
> The positive picture of a scientist emerges as follows: intelligent, educated, and studious, normal, well balanced, and not different from most other people, humanitarian with a strong sense of social duty, concerned with exploring the unknown, creative and imaginative.
>
> On the other side, the negative picture is as follows: socially inept, hard to know, neurotic, queer, overly dedicated to science, has narrow interests, mildly eccentric, out of touch, idealogically deviant, both politically and in nonpolitical ideas, too intelligent, and has powerful and dangerous things within his control.
>
> When respondents were asked to guess what sort of a person a scientist might be, 62 per cent included only positive characteristics in their descriptions and only 7 per cent mentioned exclusively negative traits.

One wonders whether the image of the scientist divulged in Mead and Metraux's study is not, except for the appurtenances due science itself, that of the adolescent's image of the *scholar* per se. Who perpetrated the image of the "egghead," a term used perhaps in a mixture of contempt and envy? Certainly not the adolescent, but the term is there for the adolescent to use and to recognize for what it is, an evaluation of the scientist-scholar by society.

It is conceivable that the idea-type construct of a scientific per-

34. *Science, the News, and the Public.* A Report of the National Association of Science Writers, Inc. New York: New York University Press, 1958.

sonality that could be derived from the work of Cattel and Drevdahl or Roe—*l'homme moyen scientifique*, if you will—with his detachment matching his insight, his sensitivity to the significance of natural phenomena contrasting paradoxically with his failure in personal empathy, is simply the kind of individual that the scientific *metier* demands. To some extent this may be the case.

The plight of the scientist, then, seems to be a special case of the plight of the inner-directed man at the other-directed stage of social development. The virtues he represents simply are not those of the model, modern American; the students Mead and Metraux cite have assigned him approximately the status associated with his character in the contemporary world. We cannot, therefore, dismiss their negative reaction to science as merely irresponsible, frivolous, lazy, groupish, or ill-informed. In part it is all these; but in part, too, it may be due to their having perceived some things about science that are really very unattractive to them. The danger of such a picture of science, if it is proved to be as widespread as Mead and Metraux indicate, is that it may eliminate from science a large proportion of the people who could contribute most to its development and thus to social welfare.

In Summary: A Picture of the Individual "Successful" in Science

It seems rather clear that the natural scientist is of superior intelligence. This is deduced from his high level of achievement: the scientist is commonly in the top 10 per cent of his college Freshman class; generally, he earns advanced degrees. His ability to think quantitatively and to state problems mathematically is above average, as are his skills in verbal reasoning. Generally, he has high reading speed and a useful vocabulary.

Add to these characteristics the traits of successful science students in various national competitions (e.g., Science Talent Search) and we find that the scientist has originality, imaginativeness, and analytic ability. To these, add above-average manual dexterity, spatial visualization, and mechanical aptitude.

The foregoing might be summarized under the syndrome "high intellectual ability."

Investigations generally report the scientist to be a person who

has self-confidence but is, nevertheless, poorly adjusted socially; he may even demonstrate asocial tendencies. Studies show general agreement that he is introverted, or inner-directed; he is goal-oriented, disciplined, and self-sufficient. The literature seems to support the picture of the scientist as a withdrawn person, persevering, hard-working, self-sufficient, controlled. Some caution here is necessary: the scienitsts studied were mature and successful, they did not have their early development in the present cultural complex but are the products of a psychosocial environment of some forty to fifty years ago.

A PICTURE OF THE ENVIRONMENT WHICH FOSTERS CREATIVITY IN SCIENCE

Home Environment. The scientist, in the past, has tended to come from a middle-class family background, characterized generally by upward mobility in economic, occupational, and educational status. Typically, the American scientist has come from German, English, Scotch, or Scotch-Irish stock and has come from a northern or western region; the origins have been either rural or urban. He was either the eldest or only boy; his parents were native-born and furnished the scientist-to-be with an intellectually stimulating environment if only because, in many cases, the father was a college graduate and a member of a profession.

In childhood, he may have had experiences of isolation but this may have resulted in independence; in any event, he had feelings of independence from his parents.

Natural science students have been found to have lesser bent toward neurotic tendencies than those specializing in arts and humanities; the natural scientist is relatively immune to a free-floating anxiety; albeit, he may be asocial. If one assumes that these tendencies are partly based on the early environment, then one may infer from this a home environment which aids the development of this personality structure.

Note that this summary is based on studies of successful scientists; hence, the early environment is that of a socioeconomic, cultural base of the 1900–1910 period.

Early Interests. The interest in science of young people who may become scientists is shown early in life. It is not, apparently, a gen-

eral interest in science but tends to be shown first in hobbies—electronics, chemistry, radio, tropical fish. This seems to be part of a general interest in music, art, and reading. Apparently, the interest in scientific activity tends to show itself at age ten to fourteen and mainly in boys; this seems to be cultural. At about the ages of fourteen to twenty the choice of a scientific career appears to be fixed.

In general, these early interests in science appear in groups whose religions do not discourage inquiry (even though the scientist typically is not a church-goer). This again may be less true of the younger scientist.

CHAPTER V

The Status of Science-Teaching in Elementary and Secondary Schools

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Introduction

Change is the most readily noted characteristic of science education today.

The years immediately following World War II were marked by a normal amount of educational adjustment. Science teachers strove to keep their courses abreast of new developments in the field and in line with the evolving needs of a new generation. But it was after nearly a decade had passed that a series of events led to an unprecedented eruption of activity in science instruction.

During the mid 1950's American educators, industrialists, government policy-makers, and other civic-minded groups became acutely aware of the serious shortage of technically educated manpower. At the same time, an increasingly widespread uneasiness was engendered by repeated warnings to the effect that communist countries were outdistancing the free world in what was being called the "race for technical supremacy." Many vigorous groups, often supported by industrial, philanthropic, or government funds, launched a variety of intensive programs designed to upgrade American science education. Representative of such programs were those of the National Science Foundation (science and mathematics teacher institutes), the Physical Science Study Committee (radically different high-school physics), the Ford Foundation (filmed courses in high-school physics and chemistry), the American Association for the Advancement of Sci-

ence (Science Teaching Improvement Program), and the Science Manpower Project (a program of research and development in science education).

In late 1957, to add to the ferment in the field, a Russian Sputnik streaked into orbit. This greatly intensified the concern and the activities of those already engaged in the improvement of science teaching and aroused the concern of many who had appeared to be unaware of the situation. The general result has been a furor of activity directly related to scientific and technical instruction, usually well motivated, but sometimes reactionary, frantic, and ill-advised. This was part of a general swing of the educational pendulum away from a type of anti-intellectualism which, for a time, had seemed to pervade so much of American culture.

It is not the purpose of this chapter to measure or to document recent and current changes in science education. But change is identified and analyzed by comparing two or more points along a continuum. This chapter is a *status* report, intended to describe science education in public schools at the time of this writing. These pages should constitute a benchmark in science education—a reference point to help today's scholars assay changes of years gone by and to help tomorrow's scholars visualize changes as yet undreamed.

Science in the Elementary School

PATTERNS OF ORGANIZATION

Science in Self-contained Classrooms. In most elementary schools science is taught by the classroom teacher who is also responsible for teaching the other basic subjects. In many school systems the area of study is suggested by the textbook. In others, a curriculum guide outlines the scope and sequence of science instruction. Experiences built upon unanticipated events constitute a large part of the "science" in many classrooms, particularly in the primary grades. The unexpected tornado or snowstorm or fire stimulates interest and questions. Teachers and children plan activities to find answers to these questions. In the process, children are helped to formulate science concepts and to develop effective patterns of investigation. Yet, more and more schools consider a science program inadequate if it is built solely around such unanticipated events.

Departmentalized Science-Teaching. In a relatively few schools,

typically in large cities, science-teaching is departmentalized. A teacher may have several different science classes a day. The program is usually based on a long-range plan not easily adapted to the immediate interests and questions of children. In such situations science may or may not be related to children's learning in other subjects.

What Science Is Taught. The universe and all its parts are the subject matter of science in the elementary school. The National Society's Forty-sixth Yearbook[1] suggested areas of study which are found in more or less modified form in many schools today. It is not uncommon to find the content patterned somewhat as follows:

Life Sciences:	Plant Life
	Animal Life
	Human Beings and Health
Earth Sciences:	Rocks, Soils, Geological Processes
	Weather and Climate
	Earth in Space, Solar System and Beyond
Other Physical Sciences:	Machines and Engines, Forces, Motion, Energy
	Heat, Sound, Light, Other Radiant Energy
	Magnetism and Electricity
	Structure of Matter, Chemical Change

Such a pattern is not to be regarded as a teaching plan; rather, it is a helpful classification or inventory of the science concepts which can be incorporated into an elementary-school program. Some curriculum plans call for the study of each of the major categories each year; others may designate categories for study in alternate years or at other intervals.

TEXTBOOKS AND OTHER PRINTED RESOURCES

Most schools use science textbooks. Frequently there is a text for each student or for each two or three students. Sometimes schools purchase several sets of different science textbooks. Each class can then use books from several sets and of different levels of difficulty. Alert teachers make liberal use of films, filmstrips, charts, and science trade books which are available on almost every subject.

1. *Science Education in American Schools,* p. 75 ff. Forty-sixth Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by the University of Chicago Press, 1947.

EQUIPMENT AND MATERIALS

Observations, experiments, and related activities are an integral part of science. In learning science, children need both specialized equipment and materials with which to construct a variety of devices as the need arises. Many schools add to their supply of locally acquired science materials through the purchase of commercial kits of "hard to get" equipment. Schools that make best use of these kits look upon them not as the sum and substance of the science program, but rather as resources to be used in connection with a thoughtfully developed curriculum.

The kinds of materials needed for an elementary science program have been discussed in a number of basic science-education documents, including *Science Education in American Schools*[2] and *Science for Today's Children.*[3]

Science in the Junior High School

PATTERNS OF ORGANIZATION

The National Society's Thirty-first Yearbook[4] recommended a continuous science program from kindergarten through twelfth grade. However, actual requirements in junior high schools vary from little or no science to a full three-year program. Some junior high schools combine science with social studies or with health and safety. Some schools offer one or more electives, such as earth science, health and hygiene, or aeronautics. Biology is sometimes available to ninth-grade students.

COURSE CONTENT

Typical junior high schools throughout the country offer courses based on interests and everyday problems of early adolescence.[5] The compartmentalization of content into geology, zoology, chemistry,

2. *Ibid.*, p. 98.

3. *Science for Today's Children,* pp. 256–74. Thirty-second Yearbook of the Department of Elementary School Principals, Vol. XXXIII, No. 1, 1953. Washington: National Education Association, 1953.

4. *A Program for Teaching Science,* p. 151. Thirty-first Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by the University of Chicago Press, 1932.

5. Harold S. Anderson, "A Key to the Science Interests of Junior High School Students," *Science Teacher,* XXI (October, 1954), 227–30.

physics, and astronomy is less common than it was a generation or two ago. The Forty-sixth Yearbook[6] pointed out the pattern of junior high school science content as developed largely by the textbook writers and course-of-study planners:

Grade 7—Science experiences having to do with the immediately personal problems of the learner and with simple understandings.
Grade 8—Science experiences dealing with the physical and community environment.
Grade 9—Science experiences dealing with the wider social significance of science and the use of science for the control of environment.

The course of study as outlined for one large city typifies a fairly widespread conformity with this general plan:[7]

Grade 7—Getting Acquainted with Yourself
Getting Acquainted with the World
Grade 8—Increasing and Improving Our Food Supply
Improving Our Clothing and Housing
Making Work Easier
Grade 9—Speedier Transportation
Improving Communication
Our Atomic World
Prolonging Your Life
New Worlds To Conquer

When general science courses are organized in a three-year sequence there is often a spiral arrangement requiring instruction in the same areas in each grade but at a different level of difficulty and from a different perspective. The New York State outline[8] illustrates this pattern:

Area	First Year	Second Year	Third Year
I. Kinds of Living Things	Living Things Around Us	Plant and Animal Habitats	Tiny Plants and Animals
II. Keeping Healthy	Taking Care of Ourselves	Foods and How We Use Them	The Body in Action
III. Using Electricity	Electric Circuits	Magnets at Work	Electricity at Work

6. *Science Education in American Schools, op. cit.*, p. 158.

7. Alfred D. Beck, "Progress Report on the Development of General Science Curriculum Program in the Public Schools of New York City," *Science Education*, XL (March, 1956), 134–36.

8. *Science 7-8-9. Suggestions for Developing Courses of Study in General Science for the Early Secondary School Grades*, p. 34. Albany, N.Y.: Bureau of Secondary Curriculum Development, New York State Education Department, 1956.

Area	First Year	Second Year	Third Year
IV. Lifting and Moving things	Overcoming Gravity and Friction	How Airplanes Fly	Traveling on Wheels
V. Common Chemical Changes	Fire	Working Safely with Chemicals	Chemical Changes in Everyday Life
VI. Energy from the Sun	Making Use of Light	Sunlight and Green Plants	Living with the Atom
VII. The Atmosphere	Air at Work	Living in an Ocean of Air	Weather and Climate
VIII. The Earth and Sky	The Change of Seasons	Some Neighbors of the Earth	Keeping Time and Locating Places
IX. Rocks and Soil	Natural and Artificial Rocks	Changes in the Earth's Surface	Water and Its Uses
X. Survival of Living Things	Flowers and Seeds	Life Cycles of Animals	Conserving Forests and Wild Life

METHODS OF INSTRUCTION

Statements of objectives of courses in general science indicate that the development of skills in critical thinking, of scientific attitudes, and of appreciation are considered as important as the understanding of basic concepts. If these objectives are to be achieved, the teaching must be consciously directed toward their attainment. The raising of problems and the pointing out of implications and applications of science should be a part of each day's instruction.

Lecture demonstrations have been in common use as a method of instruction for many years. However, the emphasis on learning-by-doing and the use of the science project have stimulated an increased interest in student activities in general science.[9]

MATERIALS OF INSTRUCTION

Textbooks in general science are commonly written in series specifically for Grades 7, 8, and 9 rather than as separate books for a single grade level. The books are becoming less encyclopedic. Textbooks are used more and more as sources of information relating to problems being studied rather than as literal outlines of the course of study. Publishers have improved their appearance by designing attractive covers and by the liberal use of color in print and in illustrations.

9. Herbert Smith and Nathan A. Washton, "Science in Secondary Schools," *Review of Educational Research*, XXVII (October, 1957), 345.

Science in the Comprehensive High School

COURSE OFFERINGS

The most commonly offered courses in a comprehensive high-school science program are general science, biology, chemistry, and physics. General science and biology are the only sciences studied by a large fraction of our present high-school population.[10] The more general variety of science course is increasing in junior and senior high schools.[11] However, the actual enrolment in the academic subjects such as biology, chemistry, and physics is the highest in the nation's history.[12]

A wide variety of science courses is offered in schools today. One study[13] lists twenty-one courses, including physiography, related physics, aeronautics, psychology, radar, time and space, conservation, and household science. In California[14] 60.8 per cent of four-year and senior high schools require two semesters of science; 14.4 per cent require three semesters; 7.4 per cent require four semesters.

METHODS OF INSTRUCTION

Numerous studies have attempted to determine the relative merit of the individual laboratory and the lecture-demonstration method of teaching science.[15, 16] Both methods have merit. Traditional biol-

10. P. G. Johnson, "Occurrences of Science Courses in American High Schools," *Bulletin of the National Association of Secondary School Principals,* XXXVII (January, 1953), 21.

11. Norman Anthony Flannigan, "A Study of High School Courses in Grades 9-12 Designed for General Education." Unpublished Doctor's dissertation, Cornell University, 1954.

12. Kenneth E. Brown, "National Enrollment in High School Science," *Science Teacher,* XXIII (March, 1956), 89.

13. Norval E. Adams, "Status of Science Instruction, 1946–1956," *School Science and Mathematics,* LVI (December, 1956), 751.

14. *Science Instruction in California High Schools,* p. 6. Bulletin of the California State Department of Education, XXIV, No. 3 (July, 1955). Prepared by the Bureau of Secondary Education in co-operation with the Subcommittee on Science Instruction of the California Association of Secondary School Curriculum Co-ordinators. Sacramento: State Printing Office, 1955.

15. Harry A. Cunningham, "Lecture Demonstrations versus Individual Laboratory Method in Science Teaching: A Summary," *Science Education,* XXX (March, 1946), 70–82.

16. George G. Mallinson and Jacqueline V. Buck, "Survey of Research in Secondary School Science Education," *School Science and Mathematics,* LV (June, 1955), 439–45.

ogy, chemistry, and physics make extensive use of laboratory work. More demonstration than laboratory work is carried on in the general science courses. The directed type of laboratory exercise is apparently giving ground to the investigative type.

The length of the typical class period is fifty-five minutes. In most schools the basic text appears to dominate the science offering. Teachers continue to use standard science equipment, filmstrips, slides, models, charts, and transparencies. Educational television is still in its infancy.

CURRENT DISSATISFACTION WITH THE CURRICULUM

Within the last five years there has been a trend in some school systems toward scheduling, one year earlier than previously, courses in biology, chemistry, and physics. Moving each subject downward one year leaves room for enriched science programs in the twelfth grade.

Science in a Science-oriented High School

The science-oriented high school is not a new phenomenon on the American scene. However, its pattern has not been thoroughly developed nor its principles completely accepted. This section is not a survey of science-oriented high schools as a group, but a description of one such institution.[17]

ORIGIN AND OBJECTIVES OF THE BRONX HIGH SCHOOL OF SCIENCE

The Bronx High School of Science was established in 1938 by the New York Board of Education for young people of high mental ability and with a marked interest in science and mathematics. The school strives to provide a broad general education for its students. While the school resembles other high schools in that it provides a general secondary-school education, it differs in that it emphasizes science and mathematics for all students. The Bronx High School of Science is not zoned; it accepts qualified students who live anywhere within the city boundaries. Admission is governed by a selective process which presently admits about one-fourth of the applicants.

17. Adapted from Proceedings of the Thirtieth Annual Conference of the Secondary School Board, New York Board of Education, March 2, 3, 1956.

COURSE OFFERINGS AND REQUIREMENTS

The program is intended to prepare students for admission to liberal-arts colleges as well as to engineering and technical schools. Required courses are four years of English, four years of social studies, four years of basic science study, three years of mathematics, and three years of one foreign language. In addition, each student takes a course in mechanical drafting, another in science techniques laboratory (a modified industrial-arts course), and a program of art appreciation, music appreciation, and health education.

SPECIAL FEATURES

Something of the quality of the program and the means of enriching it are indicated by the following statements:

1. There is liberal opportunity for laboratory work in all science courses. Basic courses have double laboratory periods; the most advanced courses are made up of two double laboratory periods and one recitation period per week.
2. The completely equipped laboratories of the school provide facilities for various types of individual and group projects.
3. As many capable students as careful programing will permit are assigned to project classes where, under expert supervision, they work on their own investigations and experiments.
4. Participation is encouraged and guidance provided in the preparation of exhibits and for competition in science fields.
5. The extensive extracurriculum program includes many school clubs that emphasize interests in the fields of science and mathematics.
6. There is wide use of community resources, and parent participation is cordially encouraged. Visits are made to museums, hospitals, colleges, and industrial-research laboratories. Career-guidance meetings, special speakers, panel discussions, and week-end biology camping trips are a part of the program.
7. The nonscience curriculum is enriched through foreign language clubs, a social-studies forum, and courses in journalism, dramatics, creative writing, and public speaking.

Science in the Technical or Vocational High School

GENERAL CONSIDERATIONS

This section concerns public vocational secondary education for individuals preparing for employment in the skilled trades or as technicians. The public vocational and technical high schools gen-

erally accept graduates from eighth- or ninth-grade programs, providing the candidates demonstrate an aptitude and interest in a specific vocation and are able to master the technical phases of the program.

Science is considered an integral part of the vocational-school program since a knowledge of its subject matter and methods can contribute to the realization of the school's purposes. In general, approximately half of the student's six-hour school day is spent on his trade or technical work, leaving the balance of the day for subjects of a trade-related nature and for those subjects which contribute to the general education of the individual.[18] Depending upon the method of presentation, science may meet the specifications of either related or general education. A typical student in a vocational or technical school studies science an average of three to four periods per week.[19]

In the state-operated system of fourteen regional vocational-technical schools of Connecticut, the required science consists of ninth-grade general science with classes meeting five periods each alternate week. In grades ten through twelve, a program of related science is required in which classes meet six periods each alternate week. The content of related science courses is drawn largely from the fields of physics, chemistry, and industry. Although there is similarity in content, these courses are not the traditional college-preparatory type.

In schools distinguishing between a vocational and a technical curriculum, greater emphasis is placed on pure science in the technical course. In schools which offer vocational courses for girls, the science program is usually modified slightly to offer more emphasis in science concepts which have value in both the trades and the home.

Science in the Junior College and Technical Institute

OBJECTIVES OF THE JUNIOR COLLEGE

With very few exceptions, the science offerings of the American two-year colleges tend to parallel those of the four-year colleges and

18. Clarence E. Lovejoy, *Lovejoy's Vocational School Guide.* New York: Simon & Schuster, 1955.

19. *Vocational Technical Training for Industrial Occupations,* p. 158. Report of the Consulting Committee in Vocational-Technical Training appointed by the U.S. Commissioner of Education. U.S. Office of Education, Vocational Division Bulletin, No. 228. Washington: Government Printing Office, 1944.

universities to which their graduates transfer. This is natural and commendable; students who transfer from two-year to four-year institutions must be prepared to compete with students who have already established accredited records in four-year colleges. On the other hand, a majority of junior college students do not transfer to higher institutions. Moreover, the junior college has important objectives in addition to preparation for advanced college study. In meeting these added objectives, other kinds of science courses, both general and specialized, might well be developed by community colleges and technical institutes. Yet the evidence indicates that very few such courses have been developed.

COURSE OFFERINGS AND REQUIREMENTS

The observations which follow were obtained through an analysis of catalogs of 14 representative junior colleges and technical institutes. Including special students, enrolments ranged from 400 to over 7,000. The data justify certain significant generalizations with respect to science education in these schools.

None of these colleges required all students to complete a specific course in science for graduation. Only three of the 14 colleges made mention of "a course or courses in science" in their statements of requirements for graduation. In most colleges, neither science nor mathematics is required for the Associate in Arts degree, although many of the specialized curriculums require appropriate science courses.

The usual lower division science courses are offered in each of the 14 junior colleges mentioned. Chemistry offerings range from 20 to 61 semester hours, from an introductory non-laboratory course to quantitative analysis and organic chemistry; three colleges include one or two semester courses in biochemistry. Physics is taught in every college mentioned, with a range from 8 to 35 semester hours of credit available. In addition, four colleges offer one- or two-semester survey courses in physical science.

The biological sciences are listed in different ways in the several institutions studied, although those presenting programs in nursing education tend to provide a greater variety of offerings. All of the 14 institutions include botany (3 to 15 hours), and biology (3 to 11 hours). Zoology is listed by name in 13 programs (4 to 22 hours).

Anatomy and physiology, either separately or together, are taught in 13 of the 14 colleges, with 4 to 11 hours of credit available. Microbiology is taught in six colleges, and bacteriology in nine. Only four of these colleges offer a general education course in "Life Science" or "Survey of Biological Science."

Geology appears in 10 of these colleges (2 to 16 hours). Astronomy is taught in 7 colleges, with a maximum of 6 hours. Meteorology and "Modern Prospecting" are offered in two colleges each. Courses offered in only one of the 14 colleges include Organic, Medical, and Food Chemistry; Radiological Defense; Earth Science; Entomology; Plant Pathology; Nature Study; Physics in Nursing; The Biology of California; and A.C. Electricity and D.C. Electricity.

Statistical Summary of Enrolments and Trends in Enrolments in Science Courses in Public High Schools

SCHOOLS OFFERING SCIENCE COURSES

The most recent reports available on enrolments in science courses on the national level are those from the U.S. Office of Education for the school year of 1956.[20] These data relate to the same 10 per cent sample of public high schools used by Brown[21] in a similar survey made in 1954. While these data provide a basis for assessing present enrolments and trends on the national and regional levels, the sample is not adequate for valid generalization at state levels.

Table 1 shows, by type of school for 1954 and 1956, the percentage of high schools offering specified science courses and the percentage offering those subjects at *any* grade level. The data in Table 1 refer to *schools*, not to students. Thus, in 1954, 23 per cent of public high schools offered neither physics nor chemistry. By 1956 this 23 per cent had declined to 18.2 per cent. Schools offering neither physics nor chemistry had an average twelfth-grade enrolment of 18.6 pupils and contained 4.8 per cent of all pupils enrolled in that grade in public high schools. Thus, 95 per cent of the twelfth-grade

20. Kenneth E. Brown and Ellsworth S. Obourn, *Offerings and Enrollments in Science and Mathematics in Public High Schools*. United States Office of Education, Pamphlet No. 120. Washington: Government Printing Office, 1957.

21. Kenneth E. Brown, *Offerings and Enrollments in Science and Mathematics in Public High Schools*. United States Office of Education, Pamphlet No. 118. *Washington:* Government Printing Office, 1956.

pupils in public high schools had access to one or both of these courses.

ENROLMENTS IN ALL SCIENCE COURSES

Table 2 shows the percentage of pupils in the last four years of public high schools enrolled in the designated science courses from 1890 to 1956 based on the total high-school enrolment. Caution should be used in making interpretations based on percentages. For

TABLE 1

PERCENTAGE OF SCHOOLS OFFERING SPECIFIED SCIENCE COURSES, FALL 1954 AND FALL 1956*

Courses	Per Cent of Schools Offering Courses									
	All High Schools		Regular 4-Year High Schools		Senior High Schools		Junior-Senior High Schools		Undivided High Schools	
	1954	1956	1954	1956	1954	1956	1954	1956	1954	1956
General science	..	85 3	...	85.1	..	89 7	. .	83.8	....	79.8
Biology	89	90 3	85	87 7	96	97 1	94	94.4	85	87 0
Chemistry	57	63.8	51	56.8	95	92 5	69	70.7	50	54.4
Physics	52	56 8	44	47.9	91	91.9	67	65 6	43	45.4
Neither physics nor chemistry	23	18.2	30	24.9	1	2.9	12	10.8	26	21.9

* From Brown and Obourn *op. cit.*, p 6. (Figures for 1954 rounded to nearest per cent.)

TABLE 2

PERCENTAGE OF PUPILS IN THE LAST FOUR YEARS OF PUBLIC HIGH SCHOOL IN CERTAIN SCIENCE COURSES, 1890 TO 1956–57*

Year	Percentage of Pupils				Year	Percentage of Pupils			
	General Science	Biology	Chemistry	Physics		General Science	Biology	Chemistry	Physics
1890	......	......	10.1	22.8	1928	17.5	13.6	7.1	6.8
1900	......	......	7.7	19.0	1934	17.8	14.6	7.6	6.3
1910	......	1.1	6.9	14.6	1949	19 9	18.3	7 5	5 2
1915	......	6.9	7.4	14.2	1954	......	19.6	7.3	4.6
1922	18.3	8.8	7.4	8.9	1956	21.8	20.5	7.5	4.4

* From Brown and Obourn, *op cit*, p. 9; and Brown, (*Offerings and Enrolments in Science and Mathematics in Public High Schools*), p. 8, Table 2. (Figures for 1956 estimated on basis of this study.)

example: While the percentage of all high-school students enrolled in chemistry has remained nearly constant for more than a half-century, the actual enrolments have increased from 40,084 in 1900 to 519,900 in 1956, nearly thirteen-fold.

Table 3 shows the number and percentage of pupils in the sample used in this study that were enrolled in certain sciences and also estimates of enrolment in the same sciences for the nation. These data are to be interpreted as follows: There were 144,584 pupils en-

TABLE 3

ENROLMENTS IN CERTAIN SCIENCES AND THE RATIO OF THESE ENROLMENTS TO ENROLMENTS IN GRADES IX–XII AND TO ENROLMENTS IN GRADES WHERE SUBJECT IS USUALLY OFFERED, FALL 1956*

Subject	Sample			Estimates for United States		
	Enrolment	Ratio Grades IX–XII	Ratio Subject Grade	Enrolment	Ratio Grades IX–XII	Ratio Subject Grade
General science...	144,584	21.6	67.0	1,518,100	21.8	67 3
Biology.........	136,159	20.3	75.5	1,429,700	20.5	74.0
Chemistry.......	50,966	7.6	34.6	519,900	7.5	34.4
Physics	30,649	4.6	24.3	309,600	4.4	24.5
Advanced general science........	7,716	1.2	6.1	77,900	1.1	6.2
Other sciences....	18,277	2.7	14.5	188,300	2.7	14.9

* From Brown and Obourn, *op cit*, p. 16.

rolled in general science in the schools of the sample. This number of pupils was equal to 21.6 per cent of all pupils enrolled in Grades IX-XII and equal to 67 per cent of all the pupils enrolled in the ninth grade in the schools of the sample. On the basis of these figures, it is estimated that in the United States, 1,518,100 pupils are enrolled in ninth-grade general science. This number of pupils is approximately 21.8 per cent of all pupils enrolled in Grades IX-XII and 67 per cent of all the pupils enrolled in the ninth grade over the nation. Similar interpretations are to be made for biology, chemistry, physics, advanced general science, and other sciences.

TRENDS IN ENROLMENTS IN SCIENCE

Table 4 shows that the population of the age group, 14 to 17, increased only 9.6 per cent between 1948–49 and 1956–57 while the school population, Grades IX-XII, increased 29 per cent. In the

same interval, the total enrolment in science in Grades IX-XII increased by 37.3 per cent. Physics was the only high-school science which showed a percentage increase in enrolment that was smaller than the percentage of population increase of the 14 to 17 age group. Percentage enrolments in both general science and biology showed substantial increases over both the 14 to 17 age group increase and the increase of school enrolment in Grades IX-XII in the interval between 1948–49 and 1956–57.

TABLE 4

ENROLMENT AND POPULATION, 1948–49 TO 1956–57*

Item	Grade in Which Subject Is Typically Taught	Age of Typical Student in Grade and Subject	Number (in Thousands)		Per Cent of Increase 1948–49 to 1956–57
			1948–49	1956–57[a]	
Subject:					
General science...	9	14	1,074	1,518	41.3
Biology...	10	15	996	1,430[b]	43.6
Chemistry.	11	16	412	520[b]	26.2
Physics...	12	17	291	310[b]	6.5
Other science. . .	10–12	... .	172[c]	266	54 7
Total science. .	9–12	. . .	2,945[d]	4,043[d]	37.3
Enrolment:					
Grades IX–XII. .	....	.... .	5,399	6,963[e]	29.0
Population:					
Ages, 14 to 17....	......	....	8,703	9,541	9.6

* From Brown and Obourn, *op cit*, p. 44; *Biennial Survey of Education in the United States*, 1948–50 *op cit.*, Tables 3, 4, 7, and footnote 5, p. 6; *Bureau of the Census Bulletin*, p. 25, Nos., 98, 146, and 170.

[a] Enrolment estimates based on present study.

[b] For first-year courses in the 3 subjects. The number of pupils taking advanced courses in these subjects is small; they are included in the 1948–49 and 1956–57 enrolments.

[c] Includes "other science" enrolments for Grade IX (a very small number), which are not included, however, in the 1956–57 number.

[d] Sum of unrounded numbers.

[e] Estimates by Research and Statistics Services Branch, Office of Education, U.S. Department of Health, Education, and Welfare, Nov. 1, 1956.

CHAPTER VI

Science for General Education in the Colleges

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Introduction

Liberal education of fifty or a hundred years ago was apparently seeking about the same goals as is general education today. That is, they both have tried to help the individual orient himself in his society. Liberal education became specialized education as young people used college education to improve their financial and occupational status. As a result, colleges graduated an increasing number of trained specialists who were not sufficiently adjusted to the total life of their society. The general-education movement is an effort to re-establish education as "the formal means a society takes to subimit its members to a common set of intellectual and social experiences."[1] This education is thought of as a force tending toward social cohesion.

General-education science courses became popular in colleges during the 1930's. They were designed for the nonscience student rather than the science specialist and were most often called survey courses. They generally stressed breadth rather than depth of content and usually drew their subject matter from two or more established science fields. There was a widespread opinion, however, that these courses were unsatisfactory due to lack of depth and a tendency to emphasize facts rather than understandings. In the late 1930's and early 1940's, there was extensive experimentation with various types of general-education science courses in the colleges. These generally

1. Harold Taylor, "The Philosophical Foundation of General Education," in *General Education*, p. 20. Fifty-first Yearbook of the National Society for the Study of Education, Part. I. Chicago: Distributed by the University of Chicago Press, 1952.

belonged to one of three categories: (*a*) survey courses of improved type, (*b*) problems courses, and (*c*) cultural heritage courses.[2]

The experimental courses of survey type tended to take the form of integrated-principles courses, based on concepts, processes, and procedures that are unifying threads running through one or more science fields such as atomic-molecular theory, evolution, entropy, and scientific methodology. In some cases, however, these courses consisted largely of material drawn from a single science.[3] The problems courses were based on selected problems of human living, such as "how to maintain good health," and "man's uses of energy." The cultural heritage courses either utilized a chronological historical approach or were case study courses based on selected examples chosen from the history of science. The Research Committee on Junior College Science of the National Association for Research in Science Teaching, reporting in 1948,[4] stated that "each of the three major types is surrounded by a widely ranging group of variants, many of which tend to partake of two or all three of them." However, the same report indicates that the older-type survey course was at that time still used in the great majority of institutions.

The period since the publication of the National Society's Forty-sixth Yearbook, *Science Education in American Schools*, has seen further extensive experimentation with various types of courses. Case study courses, built in whole or in part around contemporary problems, were an outgrowth of the cultural heritage approach.[5] Problem-area courses, based on problems of concern to students and teachers within specific subject-matter areas, combined certain as-

2. W. C. Van Deventer, "Report of the Research Committee on Junior College Science," *Science Education* XXXII (April, 1948), 188–93; and "Trends and Problems in General Education College Science Courses," *Science Education,* XXXIII (April, 1949), 183–90.

3. Hubert N. Alyea, "The Single-Science Course at Princeton University," in *Science in General Education,* pp. 124–49. Edited by Earl J. McGrath. Dubuque, Iowa: William C. Brown & Co., 1948. See also Lloyd W. Taylor, "The Single-Science Type of Scientific Appreciation Course," in *Science in General Education, op. cit.*, pp. 185–93.

4. Van Deventer, "Report of the Research Committee on Junior College Science," *op. cit.*, p. 190.

5. Clement L. Henshaw, "Problems in Physical Science, Core Course I, Instructor Manual." Hamilton, New York: Division of University Studies, Colgate University, 1949 (mimeographed). See also Sydney J. French, Clement L. Henshaw, and Robert E. Todd, "General Education in Natural Science at Colgate University," in *Science in General Education, op. cit.*, pp. 39–57.

pects of the problems and survey approaches.[6] Other courses were built to stress scientific methodology, usually in connection with one of the foregoing types of organization.

The Harvard study, *General Education in a Free Society*,[7] and Conant's book, *On Understanding Science*,[8] have strongly influenced the thinking of curriculum-makers and course-planners. *Science in General Education*,[9] in 1948, summed up the more important experiments then in progress. Bullington[10] in 1949, 1951, and 1952 published important status studies of general-education college science. Miles[11] in 1951 and 1954 published annotated bibliographies of books and articles dealing with college general-education science. The Intercollege Committee on the Evaluation of Science Objectives of the Cooperative Study of Evaluation in General Education, under the auspices of the American Council on Education, from 1950 to 1953, made significant contributions in the use of current science news in teaching, and also in the clarification of objectives. These American Council reports centered upon the goal of understanding the point of view of the scientist and the things that he does.[12]

Present-Day Trends

FORMULATION OF AIMS

There is a trend toward agreement on the objectives of general courses in science. Those mentioned most frequently stress the neces-

6. W. C. Van Deventer, "Organization of a Basic Science Course," *Science Education*, XXX (October, 1946), 201–6; and "The General Biology Course at Stephens College," in *Science in General Education*, *op. cit.*, pp. 110–23.

7. Report of the Harvard Committee, *General Education in a Free Society*. Cambridge, Massachusetts: Harvard University Press, 1945.

8. James B. Conant, *On Understanding Science*. New Haven, Connecticut: Yale University Press, 1947.

9. *Science in General Education*, *op. cit.*

10. Robert A. Bullington, "A Study of Science for General Education at the College Level," *Science Education*, XXXIII (April, 1949), 325–41; "Teachers and Teaching Procedures in College General Education Science Courses," *Science Education*, XXXV (March, 1951), 92–104; "The Subject-Matter Content of General Education Science Courses," *Science Education*, XXXVI (December, 1952), 285–92.

11. Vaden W. Miles, "Bibliography with Annotations for Science in General Education at the College Level," *Science Education*, XXXV (April, 1951), 159–76. "Bibliography with Anotations of College Science in General Education 1951–1953," *Science Education*, XXXVIII (December, 1954), 366–90.

12. Paul L. Dressel and Lewis B. Mayhew, *Science Reasoning and Understanding*. Dubuque, Iowa: William C. Brown & Co., 1954.

sity for developing in students an understanding of the nature of science and the methods used by scientists. The following statements of Nagel, Rogers, and Schwab are indicative of this trend.

> The essential point is that the materials to be included for study must be carefully selected with a double end in view: to make the student competently familiar with some representative experimental and theoretical analyses of the natural sciences; and to provide him with clear examples of the operation of scientific method.[13]
>
> The new courses should mediate between the layman and the scientist, between a classical culture and a scientific civilization. They cannot do this by pouring in scientific information or formal training. They must try to give a sympathetic understanding of science and the way scientific work is done.[14]
>
> One particular theory concerning the particular particles, masses, charges and motions which constitute the atom, may, for instance, have a very limited life and a limited applicability, but the technique of seeking explanations of physical and chemical phenomena in terms of particles of some mass, charge and motion will persist as long as theories of this kind have their usefulness and continue to be capable of revision and enlargement to encompass new phenomena.[15]

A weakness in many formal statements of objectives is the absence of a clearly defined philosophy and a definition of the course-planner's concept of the learning process. Plans of action have philosophical and psychological bases, whether or not their authors are aware of them. It would seem, then, that clear statements of these bases would permit more valid evaluation of the various programs.

Harold Taylor[16] has discussed about ten labeled philosophies showing how they fall into three major categories. Better understanding of the philosophers' points of view could shed light on some debated issues and, perhaps, promote progress in the development of general-education programs.

13. Ernest Nagel, "The Methods of Science: What are They? Can They be Taught?" *Scientific Monthly*, LXX (January, 1950), 19–23.

14. Eric M. Rogers, "The Good Name of Science: A Discussion of Science Courses for General Education in College," *Science*, CX (December 9, 1949), 599–604.

15. Joseph J. Schwab, "Science and Civil Discourse: The Uses of Diversity," *Journal of General Education*, LX (April, 1956), 132–43.

16. Taylor, *op. cit.*

THE GENERAL-EDUCATION COURSE

Because programs of general education in science are less concerned with teaching a specific amount of subject matter than with its comprehension, such courses have tended to abandon the survey approach in favor of a detailed and thorough study of a few related areas, topics, or cases.[17] The emphasis has shifted from the systematic development of a discipline to an approach which is psychological, being based on an understanding of student needs. This approach may or may not be interdisciplinary.

Nevertheless, the trend is toward the selection of areas of study that form a sequential picture. This has generally resulted in a two-semester course that begins with the study of physical-science topics during the first semester. The second semester is given over to topics in the biological sciences. These biological areas become more meaningful because of the physical-science background acquired in the first semester.

For example, in the course, *Explorations in the Sciences*, offered at Hunter College,[18] the first problem in the second semester involves the nitrogen cycle. The firm grounding that the student has had in the nature of matter, including the proteins, in the first semester, permits a more sophisticated approach than would otherwise be possible. A second problem involves the development of movement in living things from protozoans through vertebrates. The first semester study of the nature of matter and Newton's laws of motion makes possible a more thorough and comprehensive approach.

SCIENCE FOR THE NONSCIENCE MAJOR

Another trend is that toward requiring the general-education science work of nonscience major students only. Preprofessional and science-major students are required to take the standard first courses in the sciences. These are considered necessary for the prospective scientist as a foundation on which to build advanced work. It is argued that the science-major student will acquire the understandings which are included in general-education science courses as a result

17. Eric M. Rogers, "Science Courses in General Education," in *Science in General Education, op. cit.*, pp. 15–19.

18. Abraham Raskin, "Explorations in the Sciences: A Preliminary Report," *Science Education*, XL (March, 1956), 120–23.

of exposure to a larger amount of scientific learning and laboratory experience. While this exemption of science-major and preprofessional students from general-education science courses is not ideal, it appears to be a necessary expedient in many cases because of the pressure of required courses.

A related trend is the administering of comprehensive examinations to entering college Freshmen in an attempt to determine their need for a general-education science course. Those who pass such an examination either receive credit for the course without being required to take it or are allowed to substitute some other science course for it. This is an attempt to adjust the college general-education science offering to that of the high school. Ideally, such a system may be good. At present, however, few high-school courses offer the kind of experience that would duplicate the college general-education offering. Therefore, exemption through examination tends to be based on the possession of factual knowledge alone and may serve only to lessen enrolment pressures in college general-education science courses.

METHODS IN GENERAL-EDUCATION COURSES

There is no definable trend in the use of laboratory or demonstration in the teaching of these courses. The methods spectrum may range from a course based on readings, in which the only method used is discussion, through courses employing discussion plus occasional lectures and demonstrations, to the far end of the continuum where the laboratory method, including open-end experiments, is a prominent feature. If a trend does exist, it is toward the adoption of a multiple method including lecture, discussion, and demonstration, with individual and group laboratory.[19]

Typical Modern Approaches

Three present-day approaches to the organization of general-education college science courses may be considered typical. These are (*a*) the logic-of-science approach, (*b*) the problem-area approach, and (*c*) the case study approach. Each of these is an outgrowth of one of the three types of general-education science courses

19. W. C. Van Deventer, "The Multidimensional Science Course," *Basic Studies Quarterly*, II (Fall, 1956), 25–29; and (Winter, 1957), 25–30.

prevalent a decade ago. The courses emphasizing the logic of science are an example of the integrated-principles courses that grew out of the old survey type. The problem-area approach is an outgrowth of the earlier problems type. And the case study approach carries the viewpoint of the cultural heritage courses.

As they are now used, each of these approaches has certain elements in common. All utilize the block-and-gap type of organization. All make some use of the history of science. And all of them give some attention to scientific methodology.

THE APPROACH THROUGH EMPHASIS ON THE LOGIC OF SCIENCE

This type of course is based on the assumption that one of the major objectives of a general-education science course is the development of an understanding of science.[20] This presupposes that science has a certain degree of uniqueness that differentiates it from other ways of viewing human experience. Furthermore, it presumes that there is a common element that can be demonstrated in any scientific activity, such as biology, chemistry, or physics. The common element is found in the structuring or ordering of the concepts of science. There are two major methods of ordering. One is taxonomic and involves the ordering of concepts into classes and the relating of classes to each other. Examples are the classification system of animals and plants in biology and the periodic table in chemistry. A second method is the ordering of scientific concepts in postulational systems. These systems consist of primitive terms, defined terms, postulates, and theorems.

Primitive terms in a postulational system are those that are used without definition. This does not mean that such terms do not have definitions but, rather, that their meanings are determined in some other postulational system. When used as primitive terms, they carry with them the meaning they have in their own system, and, because of this, they serve as a link relating the two systems. For example, terms such as "organism," "fertilization," and "progeny" are primitive terms in genetic theory. They are native to general biological theory and are defined there.

20. References relating to the logic-of-science approach: Chester A. Lawson, "Deductive Systems and the Integration of Natural Science Courses," *Science Education*, XL (October, 1956), 253–59; and *Language, Thought, and the Human Mind* (East Lansing, Michigan: Michigan State University Press, 1958).

Defined terms are generally new terms which are coined for the specific purpose of subsuming under a single term a complex of concepts and primitive terms. The terms "homozygous" and "heterozygous" are defined terms in connection with genetic theory. They are defined by statements of relations of genes. Postulates are propositions about the nature of some aspect of the universe. They are statements that affirm something to be true. Postulates include statements of: (*a*) the taxonomic units of the system, i.e., that there are genes, molecules, atoms, points, and forces, (*b*) the properties of the units, and (*c*) relationships among the units. The propositions concerning properties and relations set forth the operations of the system. These permit deduction to other statements, the theorems.

Postulational systems can be classified into two types. One is characterized by postulates that can be verified by observation. The cell theory is an example. The other is characterized by postulates that can be verified only indirectly. An example is the gene theory.

Postulational systems are not unique to science. Both religion and philosophy consist of similar systems. However, science is unique in that it utilizes a conscious method of empirically verifying the theorems which are deduced from the postulates. This results in either a confirmation of the postulates or a conscious modification of them if confirmation is not attained. The modification that results from nonconfirmation may include only a change in some of the postulates of the system, or it may result in the production of a totally new postulational system. The new system then becomes either a substitute for the deficient one or a more inclusive one, which subsumes the older system and restricts its application.

The continuity of science from generation to generation, in which the concepts of one age serve as a foundation for the development of those of the succeeding age, can be explained by the continuous modification of postulational systems.

This process of tentatively accepting something to be true, of predicting (or deducing) other things to be true as a consequence, and then testing and confirming or modifying the tentative statements on the basis of experience, is the unique characteristic of science.

To understand science a student should understand the structure and operations of both taxonomic and postulational systems and should understand that scientific theories are particular kinds of pos-

tulational systems. In order to bring about this understanding, a general-education science course should have as its major integrating content the method of ordering concepts of taxonomic and postulational systems. Various theories of science and systems of mathematics can be dealt with in as much detail as is necessary to illustrate these systems. Thus, the subject matter which makes up the content of beginning courses can be taught as completely, deeply, and effectively as desired, while helping the student attain an understanding of science in its total perspective.

THE PROBLEM-AREA APPROACH

A course of this type combines some of the freedom of the problem approach with an emphasis on principles and, at the same time, gives attention to historical aspects and scientific methodology within a limited number of selected subject-matter areas. If these areas are carefully chosen and organized, a fairly complete coverage of major scientific principles is possible. Although coverage should not be a primary goal in a general-education college science course, it may well constitute a secondary one. A student coming out of such a course with an understanding of the nature of science and the way a scientist works, together with a comprehensive knowledge of the principles in the field, is obviously better off than one who lacks this knowledge.

Experience indicates that about three problem areas are all that can be effectively dealt with in the classroom during a single semester. More may be added if students are required to do more work on their own time. The selected problem areas are studied deeply and thoroughly, rather than surveyed. Student experiences may include assigned and optional readings, individual and group laboratory, demonstrations of various types, and discussions. All of these experiences are based, as far as possible, on problems raised by students and instructor. Therefore, the specific content of any particular problem area will necessarily vary from class to class, and from teacher to teacher, even though the basic framework of the course remains the same. This variation is healthy. All experiences are, as far as possible, "open-ended" rather than based on rote learning. Facts are considered as tools to solve problems rather than as ends in themselves.

The sharp limitation in the number of subject-matter areas makes their selection a matter to be carried out with care. They must be areas in which students and instructors consistently find problems which are worthy of attention. Although student questionnaires and other research devices may be useful in finding problem areas during the initial stages of planning and organizing a course,[21] there is no substitute for experience in guiding its evolution.

Problem areas centering around the following six topics are examples of those which have been found highly functional, in that they involve problems which are appropriate to general education:

1. Interrelationships among living organisms. This includes important principles of ecology and can be given a man-centered emphasis.
2. Genetics, with emphasis on human heredity.
3. Evolution, including students' questions concerning relationships between science and religion.
4. The human body and its functioning in health and disease.
5. The nature of the universe, including the interrelationships of matter and energy, space and time, theories of origin, and the universe as man's home and the setting for his activities.
6. Science in the news. The attitudes and methods of science in terms of recent and probable future advances.

A limited number of such areas may be found to include many of the generally accepted scientific principles. In a general-education biological science course at Western Michigan University,[22] using problem areas similar to the first four listed above, more than 80 per cent of the principles listed by Martin[23] and Washton[24] are considered. In addition to these biological principles, others were identified at "deeper" levels. These included (*a*) basic assumptions which underlie all science, such as dynamism, relativeness, intergradation, and practicality, and (*b*) broad principles which serve to unify whole fields of science, such as the idea of community relationships within groups of plant and animal species living in particular habi-

21. W. C. Van Deventer, "Organization of a Basic Science Course," *op. cit.*

22. W. C. Van Deventer, "Designing a Basic Science Course for a Specific College Situation," *School Science and Mathematics*, LV (February, 1955), 91–103.

23. Edgar W. Martin, "A Determination of the Biological Principles of Importance for General Education, II," *Science Education*, XXIX (April-May 1945), 152–63.

24. Nathan S. Washton, "A Syllabus in Biology for General Education, II," *Science Education*, XXXIV (October, 1952), 227–37.

tats.[25] A similar idea in the physical-science field is that of the interrelationship of matter and energy.

In administering a problem-area course, care must be taken to prevent its becoming simply a factual survey of the areas included. The problems and questions raised by students serve to keep the problem approach alive. Emphasis on principles serves to hold it to its function of considering facts as tools rather than as ends in themselves. Finally, laboratory experiences, when provided, keep the inductive and deductive aspects of learning in balance.

THE CASE STUDY APPROACH

The case study approach is best characterized by its emphasis on a "whole situation," whether it be a historical case or an experimental problem. Users of this approach feel that too much of a student's experience with science has been an attempt to remember the facts and principles which make up the body of scientific knowledge. This body of knowledge, so deftly finished, is a monument to the labors of countless individuals, but its study gives a student little or no conception of the struggles of the artisan (the scientist) in fashioning the individual pieces. Holton refers to the artisanship of science as "private science," in contrast to the "public science" of the journals and textbooks.[26] In today's world a person is poorly educated in science unless he understands something of both aspects.

A case dealing with a whole situation is organized around a problem. This may be a small, puzzling observation such as the discrepancy which led Ramsey to the discovery of the rare gases, or it may be a new phenomenon like Becquerel's first observation of radioactivity. Cases can be organized around a broad conceptional scheme, such as the atomic-molecular theory of matter, which has involved the work of many scientists.[27] Cases can be found also in contemporary science. Most current problems in physics and chemistry are too difficult, but, in many other areas of the natural sciences, there are problems which interest students and which they can un-

25. W. C. Van Deventer, "The Use of Subject-Matter Principles and Generalizations in Teaching," *School Science and Mathematics,* LVI (June, 1956), 466–74.

26. Gerald Holton and Duane H. D. Roller, *Foundations of Modern Physical Science,* pp. 229–47. Cambridge, Massachusetts: Addison-Wesley, 1958.

27. *Harvard Case Histories in Experimental Science,* pp. 215–321. Edited by James B. Conant. Cambridge, Massachusetts: Harvard University Press, 1957.

derstand. Finally, cases may be developed in the laboratory. Students may be presented with a practical problem, such as finding the best way to reduce losses from heat ducts, or be asked to find the temperature of "dry ice" without a low-range thermometer.

How a case is used in teaching is of crucial importance. A student accustomed to looking for things to memorize will need to be reoriented. Learning the outcome is obviously not the objective, for the student may know this beforehand. The teacher needs to help him understand the basic assumptions of the investigator, to examine his thought processes, to look for beginnings of new concepts, to analyze the ways in which different hypotheses were tested, to make comparisons with methods noted in other cases, and to recognize the human element and the unscientific factors of chance and prejudice.

Sources of good cases are limited. Few scientists wrote books or papers which are directly usable, although the University of Chicago employs selections from several.[28] Most historical material needs annotating and editing. Perhaps the best collection of historical cases has been prepared at Harvard University.[29] Cases on current problems can sometimes be developed from articles in journals, such as *Scientific American*. Occasionally, a ready-made problem, like the Carolina Bays,[30] turns up.

Students add to their scientific knowledge when studying cases, but the main objective of this approach is to help them understand how scientific ideas come into being.

Preparation of Teachers

The college teacher of general-education science controls the formal instruction in science for most students in nonscience major fields. This includes students preparing to be elementary and secondary teachers of nonscience subjects. Much of the success of the course depends on the personal and scholarly qualities of the teacher. His educational philosophy must lead to sound objectives, to effective methods of achieving student growth toward these objectives, and to valid ways of measuring such growth.

28. Aaron Sayvetz, *Scientists at Work.* Chicago: Center for the Study of Liberal Education for Adults (940 East 58th Street), 1954.

29. *Harvard Case Histories in Experimental Science, op. cit.*

30. Douglas Johnson, "Mysterious Craters of the Carolina Coast," *American Scientist* XXXIII (January, 1944), 1–22.

He should be able to help plan or to accept with enthusiasm the content and general procedures of the course in which he is working. He should be able to communicate the objectives of the course to students, to show the relevance of these to their lives, to relate course content and method to these objectives, and to help students recognize their own growth in relation to them.

Breadth of training is essential for those who are preparing to teach general-education science courses, because these courses usually include content from each major division of physical science or from several areas of biological science. Some courses deal with science in historical periods other than our own; thus an instructor's background in the history of science is important. His familiarity with the social sciences and the humanities makes it possible for him to relate science to other fields and to show the impact of science upon modern civilization.

Often, no single text is used. The teachers organize the content of the course on bases which they have developed. They may write or assemble a part or all of their own materials. They may devise laboratory procedures not found in published manuals. A capacity for original thinking is, therefore, an important attribute.

For prospective teachers of general-education science at the college level, preservice training at the graduate level can probably best be handled through interdepartmental majors or by careful selection of minors and cognate electives. It may include practice-teaching of college classes under the guidance of experienced staff members.

Experience with research is essential to the general-education science teacher who would share with his students the spirit of discovery. This is a necessary part of the teacher's preservice training. It may, however, take the form either of pure science research or of research in the teaching of science. The general-education science course, itself of experimental nature, serves as a research intrument and a proving ground for new ideas. This atmosphere of continuous research will tend to keep teachers intellectually and professionally alive.

Some faculty members may have highly specialized training in a single science without the breadth necessary for general-education courses. Since the goals and methods and, to some extent, the content of general-education courses differ fundamentally from those of

courses for science majors, in-service training in such cases is essential. This may come through staff conferences, collaboration in developing course materials, summer workshops, science institutes, self-directed study, formal courses, and reading the literature in general-education science.

Some teachers who have been technically trained in science at the Ph.D. level are able to adjust to general-education college science teaching, while others are not. In general, the stronger the person is intellectually in his own field, the more readily he can adapt. Those who cannot or will not adapt have no place in general-education science. So far, most of the better teachers in the field have been those who have made such an adaptation. It is possible that, with the development of graduate training programs especially designed for general-education science teaching, there may be less need for adaptation. There will always be a place in the field, however, for the adapted science Ph.D. His presence gives a dimension to general-education science that would not exist otherwise.

Challenge of the Future

Although general-education college science courses are now well established, those who are in the field have yet to demonstrate that the courses which they have evolved produce a more consistent and functional understanding of science in the minds of nonscientists than the traditional introductory courses in pure science (e.g., physics, chemistry, botany, and zoology). It is inevitable that the products of these two kinds of courses be compared, since the requiring of some introductory "narrow field" courses is, in the minds of critics, the usual alternative to the requiring of general-education science courses. The products of the two kinds of courses are difficult to compare, since their goals are different. Nevertheless, a definitive study of comparative results should be undertaken.

There are other problems which need to be studied. We need to evaluate the various patterns of organization of general-education college science courses in terms of their products and to compare the products of the different types in order to find out whether we are doing what we think we are doing. We need to reconsider old problems, such as size of classes, laboratory *vs.* demonstration, in the light of present-day educational conditions. We do not yet have

satisfactory answers to these problems. We need to determine the practicability of modern mechanical aids, such as closed-circuit television and complete courses on film, not in terms of whether students learn as many facts through their use as through conventional teaching but, rather, in terms of their effectiveness in motivating student interest and developing skills in analytical thinking. One of the functions of general-education college science courses is orientation. Students generally go into these courses without an established interest in science. A substantial number come out determined to go on with science. This function needs to be evaluated and given its proper place in course planning and presentation.

We must not only evaluate what we are doing now but we must also continue to try out new types of course organization and presentation, new kinds of student experiences, and different blocks of subject matter in the testing ground of the classroom and laboratory. All of this demands "on-the-job" research. Only thus can we continue to find answers to our problems.

CHAPTER VII

Developing Science Programs in the Elementary School

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The Purposes

ORIGINS OF PURPOSES

The general purposes of science education have been discussed in the earlier chapters of this volume. This chapter and the one which follows, relate specifically to science in the elementary school, in which science offerings are most closely related to the total school program and thus to the objectives of the school as a whole.

The purposes of teaching science in the elementary school have their bases in the prevailing culture, in the nature of children, and in science itself. Science, its content and methods, is a part of our culture. The needs and interests of children grow out of their culture and their nature as living human organisms. Science teaching should help children meet these personal and cultural needs.

The Culture and Our Purposes. Man has always been curious regarding the world about him. His observations have enabled him to understand his environment better and to control it to some degree. Much of man's early knowledge was haphazard, unchecked, and unclassified. As time passed, men of more than ordinary curiosity began to ask questions *which could be answered in experience.* This was the beginning of science. Methods were developed to confirm or reject earlier descriptions and to arrive at new knowledge of the world that could be checked and rechecked by different people working independently. This knowledge has been carefully organized and classified. It is a part of our cultural heritage; it is a part of science. One function of the elementary school has always been to help children learn a part of what they need to know from the

world's storehouse of knowledge. In recent years this function has embraced more and more science. Scientific methods of investigation by which knowledge may be acquired and tested are now very much a part of our culture. The elementary school should help children become acquainted with these methods.

In our society many demands peculiar to a democracy are placed on all citizens, including children. One is the responsibility to help decide how scientific knowledge will be used. In a democracy, children need many experiences that will help them understand the relation of scientific knowledge to its social and technological applications. Some of the reasons for teaching science in the elementary school derive from this need.

Purposes Derived from the Nature of Children. Man's curiosity about and need to control his environment have led to greater understanding of the world. Likewise, children's curiosity leads them to explore widely. The drive to know, to explore, to investigate, which characterizes young children particularly, is so basic that it is tempting to generalize that children are inherently "scientific." It is perhaps more accurate simply to recognize that they are human organisms—children who for one or more reasons are led to explore their environment as a part of the process of maturing. In a sense children learn in a few short years much of what it took mankind centuries to learn. Suffice it to say that children are curious and that elementary science must nurture and further stimulate this curiosity.

Children have certain physical and psychological needs. They need food, clothing, and shelter. They need physical activity, knowledge of body functions, and body care. They need knowledge of the physical changes that normally occur as they grow older. Children can meet their physical and psychological needs more intelligently if they understand the principles of health, hygiene, nutrition, genetics, and energy changes. So we incorporate opportunities for children to learn these things in the programs of the elementary school, many of them in science.

Children need to learn how to learn. With knowledge accumulating so rapidly, it is most difficult to say specifically what children should know. It is certain that they will face new and different situations in the future. They will need at that time to learn what is needed to meet the new situations. Therefore, it is important to help

children learn how to learn. The methods of science are basic to sound learning procedures.

Purposes Derived from the Nature of Science. From our definition of science as verified knowledge about our world and as methods for obtaining and checking the truth of new knowledge, we can derive several purposes for teaching science in the elementary school. For example, we should help children gain knowledge and skills which will enable them to know and understand their world.

In this quest for knowledge, concept formation is a basic function. However, a related and perhaps prior purpose is the acquisition of knowledge for use in making descriptions, explanations, and predictions. Much of children's science study is aimed at finding out *what* takes place, *what* happens, *how* things happen, under *what* circumstances things happen. Such observations lead to descriptions of events and things. Scientists and children, too, are engaged in making accurate descriptions of things as they are.

But children and scientists tend to inquire further into the explanations of things. Why does water boil? Why do birds migrate? These questions call for explanations. Usually answers that are obtained are only partial, each hinging on something else which may not be possible to explain with our present knowledge or experience. Concepts which children understand help them make correct explanations.

A powerful, creative tool of scientists is the hypothesis by which they predict what will happen under new untested circumstances. Trial applications of science concepts in new situations involve predictions. There must be many opportunities for children to speculate, try out new ideas, predict, and check.

Problem-solving as a purpose has been stressed in an earlier discussion. A problem occurs to children when the concepts they possess about their world do not enable them to describe or explain or understand a situation or phenomenon new to them. Problem-solving in this sense means developing and applying concepts which adequately explain or describe new situations.

The teaching of science should help children test ideas in their own experience and understand the difference between this kind of validation of knowledge and the authoritarian or mystical explana-

tions. Through working in the ways that scientists work they will learn how knowledge is verified, confirmed, or corrected.

Finally, children should learn that some predispositions to thought and action are consistent with the spirit of science and that others are inconsistent. We refer, of course, to scientific attitudes. The importance of developing scientific attitudes suggests that concepts such as the following may facilitate learning: man's conception of truth changes; there is a cause for every effect; much knowledge remains to be discovered; and it is desirable to have confidence in scientific methods of discovery.

Among the attitudes that children may acquire through science experiences are those that lead to "questioning magic as an explanation of events; searching for an explanation of things which happen; realizing that some natural phenomena have not yet been explained satisfactorily by scientists; rejecting personification, mysticism, animism, anthropomorphism, or gossip in making explanation; changing one's ideas as the result of new evidence, . . . placing confidence in the methods and conclusions of scientists."

Since, as has been previously indicated, the objectives of science at the elementary-school level are closely related to those of the total school at this level, we look briefly at some of the purposes of elementary science suggested in the report, *Elementary School Objectives*.[1] This report of the Russell Sage Foundation places emphasis on *behavior changes* resulting from experiences in science. It is the function of elementary science to prepare children to *do* certain things and to *behave* in certain ways. The behaviors (hence the objectives) are related to (*a*) knowledge and understanding, (*b*) skill and competence, (*c*) attitude and interest, and (*d*) action patterns.

With respect to *knowledge and understanding*, a primary-grade child is able to generalize in simple terms about seasonal changes; their effect upon the way people eat, dress, and live, and their effect upon plant and animal life. An intermediate-grade child has knowledge of electrical phenomena and understands the uses of common appliances. An upper-grade child should have an understanding of the universality of change and some of its causes.

1. Nolan C. Kearney, *Elementary School Objectives*. A report prepared for the Mid-Century Committee on Outcomes in Elementary Education. New York: Russell Sage Foundation, 1953.

Regarding *skill and competence*, a primary child should be careful in crossing streets, should play safely, and should know how to deal with fire. In the intermediate period, a child is able to use simple scientific apparatus. He can operate a slide projector. In the upper grades a child knows how to repair a variety of appliances and simple machines, to drive a car under conditions permitted by law, and to care for a garden.

As to *attitudes and interests*, a primary child should exhibit inquisitiveness with regard to all aspects of his environment. In the intermediate grades, children should be interested in learning the simple scientific principles of sound, light, heat, electricity, and magnetism.

Finally, in the *action pattern* of a primary child, there should be evidence that he asks sensible questions as he seeks to satisfy his curiosity. He tends to differentiate between fact and fancy. The intermediate-grade child goes to reliable sources of information and collects data. He helps keep home and school premises clean, sanitary, and orderly. In the upper grades, for example, a child uses scientific information in a broad range of activities about the home relating to appliances, equipment, gardens, furnace, ventilation, and conservation.

We see from these few examples that, from this point of view, the outcomes or objectives of science education are constructive behavior changes in the day-to-day life of children.

Unique Contributions of Science. From the foregoing statements of objectives it is clear that certain purposes for teaching science to children are widely accepted. A quotation from a conference report summarizes the purposes and highlights the unique contributions of science to the education of children.

> Because science is of great interest to children and is ever present, its study provides a natural opportunity for children to grow in ability to solve problems . . . . This growth in ability to solve problems, then, is one of the primary contributions science can make.
>
> Through the study of science, pupils build concepts and ideas of their world which they use in interpreting it. . . .
>
> Problem solving in science involves the use of scientific habits and attitudes which include: careful observation, accurate interpretation of these observations, and skillful recording and communicating of them. It includes the habit of withholding judgment, questioning sources of information, consulting many sources, and other familiar aspects of what is commonly called scientific attitude.

> Through the study of science, pupils learn that careful collection of data is often done through the use of instruments, and realize that through the refinements of instruments, our scientific knowledge has grown. . . . It is important . . . to stress the possibilities for creativeness inherent in the use of instruments to make discoveries. Making and using science equipment is challenging to the imagination, resourcefulness, and creativeness of many children.
>
> . . . science is one of the areas in which it is essential to check ideas against empirical experience. In science, children have to check their ideas against what actually happens even though this may not always be what they would like to have happen. . . . The nature of science itself then forces pupils who study it into certain patterns of behavior that can become a most desirable part of their attitudes and habits.
>
> The cumulative aspect of science . . . that knowledge grows as it builds on other previous knowledge . . . is important for children to understand. In solving a science problem we do not start from the beginning; we use what others have discovered and build on it. This is true when pupils solve problems; it is true when scientists solve problems.[2]

Science for All Children. The importance of science experience as a part of the general education of all children in the elementary school is now widely accepted. The purposes outlined in the foregoing paragraphs are generally appropriate for all. Science experiences must not be reserved for any special group. Every child, as he comes to assume adult responsibilities in a democracy, must participate wisely in making many decisions which require knowledge of science—its contents and its methods.

Science for the More Able Pupils or for Those Interested in Science. Are there specialized purposes also appropriate for children who are especially able and highly interested in science? Quantitatively, it is expected that these children will learn more science than will the less-able pupils or the disinterested ones. But, qualitatively, the purposes are generally the same for all children. This does not imply that attention to individual differences and interests is not important. Indeed, in science are to be found rare opportunities to challenge children of varying intellectual abilities and interests. If there is one unique purpose in teaching bright children, it is to keep their interest in science alive so that many of them will choose to pursue careers in science, mathematics, and engineering.

2. National Science Teachers Association, *It's Time for Better Elementary School Science*, pp. 5–6. Washington: National Education Association, 1958.

OUR PURPOSES AND TODAY'S GENERAL CULTURE

There are several different ideas today about the function of the school in our society. Should it teach skills only, maintain the status quo, pass along the cultural heritage, or bring about cultural change? Our schools in effect attempt, in some measure, to realize each of these functions. This brings about considerable confusion.

When children study science they draw on accumulated knowledge in order to understand presently observed natural phenomena. Yet, knowledge is not learned just for the sake of learning but to throw light on children's current questions and problems. By teaching children the methods of science we are, in a sense, transmitting the culture of the past. But the methods give us the key to discovering valid new knowledge and to solving new problems.

In this century, characterized as it is by scientific and technological advances, scientific attitudes are not the motivating attitudes of a majority of our population. Most people accept scientific knowledge as valid within small spheres of their life and look to other sources of knowledge for behavior guidelines in many aspects of living. This results in a real dilemma. Children, who in science are taught to be open-minded, to be tolerant of various points of view, and not to jump to conclusions are confronted on every hand with decisions which are not to be questioned, superstitions and magic, advertising that is false and authoritative, and other evidences of unscientific beliefs and behavior. One of the greatest cultural problems which elementary-science teachers face is that of helping children see the spheres where scientific inquiry and behavior are appropriate, though perhaps sometimes not accepted.

SOCIAL IMPLICATIONS

Most science educators would say, without hesitation, that all the purposes of science instruction have social implications. Whether we think of children in their day-to-day social life or of adults in general, we can see that the attitudes we associate with science ought to affect the children's behavior, the choices they make, the ideas they express, the way they think, and the beliefs they hold. If science study does not help modify the behavior of children, this too has its social implications. It is an aim of science teachers to help children

learn to apply their problem-solving skills in situations that do not deal exclusively with natural phenomena but also with social situations. This may be too much to expect. Mature scientists find it difficult. Perhaps that is reason enough to give more serious attention to that purpose in working with children.

Children in the elementary school should have experiences in deciding how and whether to use scientific knowledge in situations of social significance. This is not to say that children should be asked to make decisions on adult problems but, rather, that they should learn to use scientific knowledge in solving problems that are not too difficult. For example, children may have knowledge of how to prevent erosion in the schoolyard. This knowledge does not prevent erosion. The question is: "Should we use the knowledge?" It is through making such decisions that children may develop the concept that it is a social responsibility of all citizens to help decide what applications of scientific knowledge are appropriate.

Children must see the need for the support of science and scientists if our present technological society is to endure. It is granted that these are mature concepts, but attitudes are formed early in the lives of children. Hence, instruction in the elementary school must work toward developing these attitudes on appropriate occasions.

We now turn our attention to the program that is intended to achieve the objectives that have been discussed in the preceding paragraphs.

The Program

HOW THE SELECTION OF SUBJECT MATTER IS MADE

Experience in the teaching of science in the elementary school has demonstrated that the most successful programs have their origin in a variety of sources: (*a*) the *child*, with his emotional, intellectual, and physical needs; (*b*) the *environment*, both natural and man-made, in which the child lives; (*c*) the *sciences*, especially biology, chemistry, physics, and astronomy; and (*d*) the *total school program*, as it relates to the needs of *society* for informed citizens, capable of participating in social living.

Curriculum-planning has sometimes drawn heavily upon one of these sources without due regard to the others. Thus, in some localities, science has been made an adjunct to social studies, whereas in

others the science program has leaned heavily on selected features of the local environment. In some instances, the science program of the elementary school has been designed as a "simplification" of junior and senior high school science. This "watered-down" approach, while generally rejected at this time, crops up sporadically in some "crash" programs which attempt to "scale down" upper-school apparatus, experiments, and ideas to "fit" young people.

Science programs drawn chiefly from one source are sometimes helpful in demonstrating the limitations of such programs. Today, however, there seems to be widespread agreement that the most vital programs are those based on the needs of the child in his environment, programs which are in harmony with the total school program and mindful of the needs of society and which utilize the materials, concepts, and methods unique to science. The process of curriculum development involves the exploration of *all* these sources to find in them the content and the methods for the science program. Curriculum projects as designed are generally prepared by teams of classroom teachers, supervisors, curriculum specialists, and personnel from teacher-training institutions and community organizations.

Owing to recent developments such as those noted, elementary-school science is now for the first time achieving full and independent status; it is no longer to be found on the periphery of other subjects in the elementary-school program; nor is it regarded as a downward extension of upper-grade science. Elementary science is now beginning to develop its own structure. It is discovering its own setting and its own problems as it develops programs drawn from each of the four enumerated sources. Let us explore individually these sources.

The Child. The curriculum in science is based on the nature and needs of children: on their delight in sensory experiences, their sense of humor, their curiosity, their concerns, their ability to generalize and to apply principles, and their urge to create. It recognizes that children are different—varying in rate of growth, in manual dexterity, in kinds of experience they have had, in the depths of their interests, and in their capacity for learning.

Children respond with enthusiasm and understanding when they are provided with wire, batteries, switches, and electrical devices like bells, lights, and toy motors and are encouraged to experiment with these materials.

Children get deep satisfaction from firsthand experiences with the forces of nature. They sense the spirit of science when their curiosity is rewarded with discovery.

As teachers, we get clues to science content when we listen intently to children's questions. We get other clues from our observations of toys they play with, the way they spend their afternoons, the television programs they watch, the books they select for reading, the sports and hobbies they engage in, the responsibilities they accept at home, and the pets they take care of.

The science program should encourage creativity and originality in the activities of children. These traits may be fostered by providing materials and situations which permit children to investigate problems and practices which are new to them, and which encourage creative expression reflecting their individual talents and capacities.

The Environment. As has been indicated earlier, one of the important values of science in the elementary school is that it contributes to the child's understanding of his immediate environment at a time when he is most curious about it and most ready to explore it. The typical questions asked by children illustrate this breadth of curiosity.

It follows that each school should build into its curriculum the peculiar features of its own environment. The near-by river, the "empty" lot, the park, the brook, the swamp, the tree on the street, the vegetable market, the bakery, the flower shop, the large gas tanks, the school bus, all these are resources that can be utilized.

The Sciences. We have observed how elementary science stems from the needs of children and how it flourishes when it is rooted in their environment. However, the uniqueness of elementary science is derived from the content of organized knowledge and the methods of discovery inherent in the formal sciences.

In designing the elementary-science curriculum we look to the basic sciences for both answers and questions. We look to biology, physics, chemistry, geology, and astronomy for answers to questions arising out of the total life of the child; we seek answers that furnish facts, concepts, principles, techniques and materials, approaches and methods. We look to these sciences also for key questions which will lead children into the structure of organized science. Science gives information; it furnishes concepts and principles; it suggests techniques and materials; and it provides approaches to problems and

methods of thinking. Science asks questions. While rejecting the idea that elementary science is a watered-down version of the science of higher levels, we should not disregard the opportunities which present themselves for using guide lines which may help lead young people into the formal sciences. When, for example, we encourage children to discover that shape has something to do with buoyancy, we are starting them on the way to an understanding of the principle of flotation. When children are led to uncover, layer by layer, the disintegrating leaves of a forest floor, they are on the road to understanding the cycles which make life on earth possible. When they experiment to find out how to make their electromagnets more powerful, they are acquiring concepts which will be useful when they study electromagnets in advanced courses.

We find the clues to problems like these by looking for them in the structure and history of the various sciences, in their methods of discovery, and in the important concepts and principles which run through them. Incidentally, the study of the history of science is especially fruitful in suggesting many experiments which represent great triumphs of scientists, yet, which children of today can perform and understand.

The search for these guide lines to the sciences is facilitated when curriculum teams include individuals who have had training in the various sciences. For example, personnel from high school and college should be included; perhaps doctors, engineers, geologists, and chemists of the community may help; so, too, may representatives of scientific, technical, and business institutions. From the use of teams of such diversified membership a broader understanding of the problems at all levels may result.

In the last decade there has been a strengthening of the sequence for science from Kindergarten through Grade XII. Articulation between the various levels is being advanced as the elementary schools look more intently at the science content of the upper grades and expect to include these observations in their planning. Articulation is also strengthened as the philosophy of the junior and senior high school embraces more of the educational values which the elementary schools have found so invigorating in the last three or four decades.

The Total School Program. A basic premise underlying the sci-

ence program is that it should be in harmony with the total program of education. This implies that elementary science is an integral part of the fabric which includes social studies, language arts, music, mathematics, art, and health education. Science brings new strength to the elementary schools. Its methods, its approach to problem-solving, and its informational content enrich the whole program and give it new scope and depth.

Social studies, which in Kindergarten through Grade VI includes geography, history, and civics, is, of all subjects, the one most closely allied to elementary-school science. Its concern with problems of living and working together in the home, school, neighborhood, community, or country makes social studies a good background for many science activities. Communication, transportation, food, clothing, shelter, water supply, are topics which are shared by social studies and science.

"If in the social studies, for example, a class is studying the buildings and building construction in their neighborhood, questions with science implications will undoubtedly arise. The children will want to know about some of the materials used—wood, rock, iron, glass, bricks, sand, cement—their origin, their preparation for use, their qualities. . . . They may be interested in some of the machines—wheels, levers, gears—that move things. They may explore the ways in which buildings are protected from the weather. As they watch men at work connecting utilities to the building, they learn about water, sewage, electricity, and telephones."[3]

But supplying information is only one of the contributions that science makes. Science vitalizes units by encouraging children to raise questions and to find ways of answering them. When children are permitted to experiment with materials and to find out, for example, why steel bridges and iron fences are painted, how concrete is made and used, why a lever makes some kinds of work easier, why water rises in the pipes of a tall building, or why electric wires are insulated, they are doing more than talking about science; they are living it.

Science is allied to mathematics because of its emphasis on measurement, accuracy, and numerical relationships and because it sug-

3. *Science, Grades K-6.* Curriculum Bulletin #3, 1958–59 Series. New York City Board of Education.

gests many uses for mathematics in real life situations. Using instruments such as the thermometer and the rain gauge and making calculations required in planning models for a planetarium are illustrations of the use of mathematics in science.

Science makes use of language arts and art skills. Reading, writing, listening, speaking, painting, and sketching are essential tools in elementary science. Here again, the necessary skills are developed by the science program as the child needs them.

The foregoing observations do not mean that science serves only to enrich other areas. Science is the center for many units of planned, co-ordinated experiences, organized around central scientific themes and problems. These science-centered units draw on skills and knowledge from the other curriculum areas as need indicates; but their over-all focus is on science.

ORGANIZING THE PROGRAM

The Structure. The National Society's Forty-sixth Yearbook pointed the way to the organization of the elementary-science program, stressing the importance of acquainting pupils with the broader areas of the physical and biological environment by introducing such subjects as the universe, the conditions necessary to life, living things, physical and chemical phenomena, and man's attempts to control his environment.[4]

During the last decade, elementary-school science has succeeded in developing many vital experiences for children within these broad areas and in suggesting sequences of unifying concepts from the kindergarten through the sixth grade. A wealth of content in science is emerging as a result of the efforts of classroom teachers, science specialists, curriculum workers, college teachers, and writers of children's books. Although science programs vary markedly from place to place, content areas such as the following appear in many curriculums: living things, earth in space, communication, transportation, resources of the earth, magnetism and electricity, weather, machines, changes in the earth, and health.

These areas—or similar ones—are broad enough to serve as centers

4. "Organization of the Curriculum in Science," *Science Education in American Schools*, pp. 75–76. Forty-sixth Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by the University of Chicago Press, 1947.

for organizing many experiences and activities to meet the needs and interests of children and, at the same time, are rich enough in science content to provide for sequential mastery of science concepts and principles.

Different schools and school systems allocate content to individual grades in different ways, depending on various factors, such as basic philosophy or the nature of the experience of their teachers. Some have divided the content to provide specific teaching materials for each of the grades, Kindergarten through Grade VI. Other schools or school systems have organized the content for groups consisting of two or more grades, as for example, Kindergarten-II, III–IV, and V–VI. This broader grouping permits great flexibility in developing science instruction while providing for a measure of continuity.

The different ways that school systems have organized their science programs are illustrated by descriptions drawn from the curriculum guides and resource bulletins of a number of the larger state and city school systems.

Baltimore.[5] In the Baltimore public schools elementary-school science is included with social studies and the areas of health and safety. The program correlates curriculum experiences which contribute to the development of social maturity. It includes classes from the Kindergarten through Grade VI. A carefully selected list of topics helps identify the content of the social-living areas: (*a*) understanding, conserving, and utilizing man's physical environment, (*b*) protecting life and health in the world today, (*c*) improving man's living conditions, (*d*) providing for and appreciating aesthetic expression, (*e*) recognizing and appreciating our cultural heritage and the interdependence of all people, (*f*) understanding and developing an appreciation of the responsibilities of citizenship and, (*g*) developing moral and spiritual values.

Within the social living areas there is provision for sequential growth in science from the Kindergarten through Grade VI. The following topics are taken up: growth of living things; effect of weather, atmosphere, and climate; the solar system; forms of energy and their uses; scientists and scientific ideas.

5. *A Guide to Elementary Education.* Baltimore, Maryland: Baltimore Public Schools, 1955.

Cleveland.[6] In the kindergarten, content is within the environment and experience of young children. Such topics as pets or signs of fall are included in its science program. In Grades I, II, and III science is integrated with social studies and with health and safety. Units based on these subjects are taught about one hour daily. In each semester about six weeks of daily one-hour periods are devoted to science-centered units. The following are the science units designated for the first three grades:

Grade I. 1. Changing Seasons—Effects on Plant and Animal Life
2. Pets

Grade II. 1. Transportation
2. Domestic Animals on the Farm
3. Weather
4. Night Sky

Grade III. 1. Wild Animals around Cleveland
2. Rocks and Soils around Cleveland

In Grade IV, two forty-minute periods of science are required weekly; in Grades V and VI, three forty-minute periods are required. The following units are included:

Grade IV. 1. Classifying Plants and Animals
2. Cause of Night and Day, and Seasons
3. Experiments with Magnets
4. Conservation—Wild Flowers of Spring

Grade V. 1. Interdependence of Living Things
2. Weather
3. Physical Science Units—machines, heat, chemical and physical changes

Grade VI. 1. Earth: Kinds of rock, erosion
2. Prehistoric Life
3. Electricity, Light, and Sound
4. Atomic Energy
5. Space Travel

Louisville.[7] A large amount of resource material has been organized in two major grade blocks, Kindergarten-Grade III and Grades IV-VI. The following are the topics included.

Kindergarten–Grade III. 1. Weather and Climate
2. Story of the Earth
3. Living Things
4. Health and Nutrition
5. Machines and How They Help Us
6. Magnets and Electricity
7. Light and Sound

6. *Mathematics and Science in the Cleveland Public Schools.* Cleveland, Ohio: Board of Education, 1957.

7. *Science Source Book.* Louisville, Kentucky: Board of Education, 1954.

Grades IV–VI 1–7. Same as above, plus
8. Matter and Energy

Washington, D.C.[8] The following represents the units covered in the Washington, D.C., schools:

Living Things—Grades K-II, III-IV, V-VI
The Earth—Grades K-II, III-IV, V-VI
The Universe—Grades K-II, III-IV, V-VI
Weather—Grades K-II, III-IV, V-VI
Aviation—Grades K-II, III-IV, V-VI
Energy and Machines—Grades K-II, III-IV, V-VI
Water—Grades IV, V-VI
Sound—Grade V
Magnets—Grade V
Electricity—Grade VI
Light—Grade VI

New York City.[9] Resource materials are provided for each of the following seven areas in continuous sequence from kindergarten through the sixth grade. The material which follows is studied in the following grade categories: K-II, IIII, IV, V, and VI.

1. Magnetism and Electricity
2. The Earth in Space
3. Living Things
4. Communication
5. Weather
6. Transportation
7. Earth and Its Resources

New York State. The science content is now being organized in ten areas from the kindergarten through the ninth grade to provide for sequential development in each of these areas. For the elementary school the activities are being set up in grade blocks on a K-II, III-IV, and V-VI basis. The ten content areas are:

1. Kinds of Living Things
2. Survival of Living Things
3. Keeping Healthy
4. The Earth and Sky
5. The Atmosphere
6. Energy from the Sun
7. Rocks and Soil
8. Lifting and Moving Things
9. Using Magnetism and Electricity
10. Some Common Chemical Changes

8. *Elementary Science Curriculum.* Washington: Board of Education, 1957.
9. Science: Grades K-VI. Curriculum Bulletin #3, 1958–59 Series.

Advantages of Structured Program. Those who advocate an unstructured program in elementary science argue that teachers should be guided solely by the interests of the children. They regard a course of study as stultifying and unnecessary. There is no question but that some excellent teaching has been done without a structured program in a number of small school systems, particularly in those in which science consultants were available or in which the teachers have had an unusual background in science. However, the claims for a structured program are more compelling.

a) A structured program provides a framework of science principles which can help teachers unify their own experiences and give them confidence in meeting difficult classroom situations that arise. The answer suggested a decade ago to children's questions—"I don't know, but let's find out together"—is not sufficient for all of today's needs.

b) A structured program does not have to be a rigid one. Within the broad content areas, there are many choices which permit the teacher to adapt the program to the needs of the class. Both the unit approach and the provision of a variety of materials and situations which foster children's creativity and originality are possible within a structured program.

c) The freshness engendered by the use of unanticipated incidents is not lost in a structured program. Indeed, the incident becomes more significant because the teacher sees it as a part of the whole and thus may be able to convey its importance to the pupil. A structured program helps the teacher anticipate, identify, and incorporate into the program the many incidents which arise during the school year.

d) While it is true that children come to school with many interests, it is also true that interest can be aroused and cultivated by what takes place in school.

e) A structured program makes it easier for children to acquire the science concepts essential for their understanding of the complex world they live in.

f) A structured program is a democratic one: Many can share in building it and in changing it. It provides a common framework for testing and evaluation by the children as well as by the teachers.

The Sequence. Elementary science can serve the general purposes of elementary education as well as its own unique purposes, if its content provides for children's growth in their understanding of science concepts and principles. Studies of children's development provide clues to the order of complexity of science concepts. Some

of the following generalizations have been found helpful in guiding the organization of sequence:

a) The child's view of the world begins with the here and now and extends to the far away and long ago.
b) The child grows in ability to reason, to generalize, to apply principles, to see cause-and-effect relationships.
c) As the child develops physically he is able to participate in activities requiring greater strength and dexterity.
d) The child's increasing capacity for comprehending such dimensions as time, distance, size, speed, direction, or weight may influence sequence.
e) Strong motivation provided by current interests and the special character of the local environment may sometimes outweigh other considerations in the determination of sequence.
f) Sequence will be influenced by the desirability of taking into account the science to come in the upper grades.

Sequence is something that must be tested and judged in the setting of the entire program. Continuous experimentation and careful observation are fundamental to growth in knowledge about what is most appropriate at a specific level.

Having explored the objectives and the program, let us now give attention to evaluation of the program. Chapter viii will deal with evaluation of the pupils' growth.

THE EVALUATION OF THE PROGRAM

A program in elementary science can be effectively evaluated only when the objectives of the program are clear and have been accepted by the teachers and administrators in charge of the program. Too often the goals of a program are listed by a committee, printed at the beginning of a course of study, and then forgotten. Once goals have been accepted, they should be used as a basis for the selection of subject matter and the methods of teaching. If this is done, the adequacy of the program may be evaluated, at least in terms of its goals. Such appraisal may lead to redefinition of purposes and the establishment of new goals, which in turn may reasonably be expected to lead to experimenting with different teaching methods and subject matter. This is a process by which educational programs can be improved continuously.

Many curriculum guides and resource units include suggestions

for evaluation. Some of the manuals for the development of courses of study that have been produced by state departments of education contain excellent suggestions for evaluation. However, few systematic attempts at evaluation of elementary-science programs have been reported. Ashley[10] used a historical approach to identify the critical factors involved in the development of an elementary-science program in a community.

Boyer[11] used standardized achievement tests and a direct-approach test, with experiments demonstrated before groups of children, in order to compare the effectiveness of two different kinds of science programs. Obviously, more such studies are needed to provide better guides for evaluation.

Who Evaluates? If the evaluation of a total program in elementary science is sought, then all who participate in the program should be involved in the evaluation of it. Too often segments of the program have been evaluated in discrete units only by those most closely connected with the particular parts examined. For example, fifth-grade teachers in a school system have regularly evaluated the science taught in the fifth grades only. At times, the evaluation has been limited to the appraisal of the elementary-school program in science by the elementary-school faculty. This is too limited a group to evaluate elementary science as an integral part of a science program extending from the Kindergarten through Grade XII. A total science program must be assessed by elementary- and secondary-school teachers, by consultants in elementary science if they operate in the system, and by those administrators who are responsible for the development of curriculum. These are the persons primarily responsible for the selection of methods and content. All must be involved in the evaluation of the acceptability of the elementary-science program.

But the learner must not be forgotten. He must have a part in the evaluative process. Involving elementary-school children in assessing the *program* in science is a difficult undertaking, since their appraisal

10. Tracey Ashley, "The Development of Science Program in Childhood Education in the Elementary School." Unpublished doctoral project, Teachers College, Columbia University, 1958.

11. Donald Allen Boyer, "A Comparative Study of the Science Achievement of Pupils in Elementary School," *Science Education*, XXXIX (February, 1955), 3–12.

is apt to be related only to their most recent science experiences. Even so, the judgment of children may lead to reappraisal of a program. Older children, especially those in the upper-elementary grades and in the secondary school, may be used in helping the teaching and curriculum staffs find strong and weak features of the elementary-science program.

A third group sometimes involved in judging the merits of a program in elementary science is composed of parents and other members of the community. Often, they make judgments of the value of various aspects of the science program. At times, their judgments result in pressure being applied to influence school programs. The evaluation by members of the community may contribute to the over-all evaluation of the elementary-science program.

The teacher and administrator have the responsibility of weighing and co-ordinating the various evaluations of the elementary-science program. Children, teachers, and other members of the community all express their views about the program. To make a difference, however, evaluation must affect the program. To use evaluations to modify and improve programs is a task for the administrators—who are responsible for the development of programs of elementary science.

When and How Should Evaluation Take Place? If a program in elementary science is to be dynamic, if it is to make a difference in the lives of children, then that program must undergo careful and constant scrutiny. But, planning for the evaluative process must also be an integral part of the program in elementary science. This process must not be left to chance, to be considered in a cursory manner every few years by a committee of teachers. Ongoing and thorough examination of a science program should be considered part of the educator's responsibility, and there should be adequate provision for meeting this responsibility.

A description of the procedure for involving responsible personnel in evaluating the program follows: In one local school a group of three teachers, one who taught five-, six-, and seven-year-olds, one who taught eight- and nine-year-olds, and one who taught ten- and eleven-year olds, were the nucleus of a committee for the evaluation of the science program in each elementary school of a system. These

three teachers had the responsibility for gathering information from their co-workers each eight weeks. Such information was gathered verbally or in writing and included responses to the following questions: What content, methods, or materials have you used or would you like to use? Have you evidence that your present group of children is making use of previous experiences? Have you evidence that your children are strengthening their insights and expanding their interests in science? If so, what is making this possible? What improvements are you planning to make in your own science program? What improvements would you like to see made in our total school program in science?

Such information is invaluable in appraising a school's science program and as a basis for its improvement. With such information, committees of teachers and administrators can plan a series of meetings with the total teaching staff. Such meetings can lead to continuing improvement of the science program in the elementary school.

For such important curriculum work, leadership is needed to organize the evaluation and to find means to insure that the outcomes of the evaluative process are reflected in the developing program. Adequate periods of time must be planned for evaluation, and administrative and secretarial assistance should be provided to facilitate the work of the committees. The machinery must be set up so that representatives of various groups of teachers and administrators can work together on evaluation.

Some Characteristics of a Good Elementary-Science Program. Each teacher, each elementary school, and each school system is responsible for determining the goals toward which science-teaching and learning are directed. It follows that each teacher, school, and school system must be intimately involved in judging the appropriateness of the goals and the methods and materials employed in reaching those goals. Science programs will vary from community to community and certainly will change with the passage of time. It seems appropriate, however, to present the following characteristics of a good elementary-science program, together with the criteria for evaluation in the hope that they will be of specific aid to educators in judging their programs.

CHARACTERISTICS OF A GOOD ELEMENTARY-SCIENCE PROGRAM	CRITERIA FOR EVALUATING AN ELEMENTARY-SCIENCE PROGRAM
Elementary science should be recognized as an important part of the total elementary-school curriculum. Science experiences should be a part of the total school experiences at each grade level. Elementary-school science should be an integral part of a K-12 science program.	Is sufficient time for science provided in the program? (Some educators are suggesting that one-fifth of the elementary program be devoted to science, one-fifth to social studies, one-fifth to language arts, one-fifth to expressive and graphic arts, and one-fifth to the development of skills related to learning.) Has a curriculum in elementary science been developed for your school? Do the science experiences at each grade level build upon experiences in previous grades and lead to experiences in subsequent grades? Is an administrator responsible for assisting teachers in developing the science program from the Kindergarten through Grade XII? Are parents regularly informed of the achievement of their child in science?
A program in elementary science should be provided for *all* children.	Do the teachers and administrators view science as important in the life of each child? Realizing that all citizens must be aware of and understand the importance of science in a democracy, is a science program provided for all children? Is opportunity provided to extend the horizons of those children who are especially fascinated with science?
The development of scientific attitudes is basic in a good elementary-science program.	Do teachers provide time for the exploration of ideas verbally and with materials? Is there evidence that scientific attitudes are becoming a part of the behavior of children?

CHARACTERISTICS OF A GOOD ELEMENTARY-SCIENCE PROGRAM—*continued*	CRITERIA FOR EVALUATING AN ELEMENTARY-SCIENCE PROGRAM—*continued*
An elementary-science program should provide a balanced content in science.	During each one- or two-year period, do children have an opportunity to explore in each of the several large areas of science, such as (*a*) our earth, its composition, and the changes occuring on it; (*b*) our earth in space; (*c*) the living things on the earth, how they grow, change, survive, and die; (d) the physical and chemical forces man uses; (*e*) man's place in his changing environment?
Children need to have an opportunity to participate in a variety of activities in elementary science.	There is no one best way to develop elementary-science experiences. A good elementary-science program is characterized by a variety of challenging experiences. Do children have a chance to participate in experiments, demonstrations, field trips, construction projects, library research, group discussions, and discussions with informed members of the community? Is the curriculum flexible enough to provide time for investigating important science questions not provided for in the planned program in elementary science?
Adequate materials are provided to carry on a good elementary-science program.	Are appropriate manipulative materials provided as regular equipment in each classroom? Is provision made for exploration of the out-of-the-classroom environment? Is each classroom provided with a science library of at least two different books per child? Is there a selection of science books in the school library?

CHARACTERISTICS OF A GOOD ELEMENTARY-SCIENCE PROGRAM—*continued*	CRITERIA FOR EVALUATING AN ELEMENTARY-SCIENCE PROGRAM—*continued*
	Are films, film strips, TV programs, slides, records of bird songs, etc., readily available?
Expert help is available to the classroom teacher, who is the key to a good elementary-science program.	Are professional books and curriculum materials in science provided for teachers?
	Is some one administrator responsible for aiding teachers in the development of a program in elementary science?
	Is a consultant in elementary science available for each group of 18 to 24 classroom teachers in the school system to aid them in their work? Is this consultant trained both in working with elementary-school children and in science content?
	Are opportunities available to classroom teachers for in-service education in science?
Ongoing evaluation is a part of a good program in elementary science.	Is provision made for constant and thorough analysis of the elementary-science program?
	Has the program in elementary science been improved substantially during the last two years?

These are some characteristics of good elementary-science programs. Committees of elementary-school teachers and administrators working in co-operation with teachers and administrators from other schools in the school system can use those characteristics to examine and evaluate their programs of elementary science. Such evaluations can lead to the continuing improvement of children's experiences in this important area of the total elementary-school program.

CHAPTER VIII

Teaching and Evaluating Science in the Elementary School

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In the preceding chapter we have examined the purposes and the program of science in the elementary school and have considered evaluation as it relates to the program. In this chapter we shall consider some features of the methods of instruction and also of evaluation as they relate to the teaching process.

The Teaching Process

Obviously there is no *one* best method for teaching science in the elementary school any more than there is *one* best way to teach any other subject. We shall, however, attempt in this chapter to set forth some principles that, if observed, will raise the level of science instruction. They are practiced wherever there is good science-teaching. They are in accord with what we know about children and learning.

OBSERVING THE GOALS

Obviously our primary concern with any method of science-teaching is that it be designed to motivate the learner toward achieving the accepted goals. The goals of science education are designated elsewhere in this yearbook. They are listed and discussed frequently in the literature; but examination of practices indicates that many teachers do not take them into account in determining methods of instruction. If pupils are to grow in ability to solve problems, in scientific attitudes, and toward the realization of the other aims of science-teaching, the instruction must be so designed that the attainment of these objectives will result from the methods employed.

PROBLEM-SOLVING

Greater effectiveness in science-teaching is almost sure to result if the learning begins with a perplexing problem—one for which the learner is motivated to seek a solution, either because he has generated his own perplexity or because his teacher has stimulated him to wonder. The problem, then, becomes the motivating factor, and curriculum activities are performed only to solve the problem. The purpose gives focus to the method. It makes selection of the activities clearer; it makes evaluation easier.

Problems to be solved may come from a variety of sources. They may be presented by the pupils; they may be suggested by a current happening; they may come from the teacher, from the textbook, or from a prescribed course of study. Whatever the source, learning will be more effective if pupils become genuinely interested. As has been indicated elsewhere in this yearbook, these problems should constitute a developmental program as the pupils progress through the school.

THE ACTIVITIES

Faced with a problem, the solution of which appears important, pupils are motivated to respond to the question, "How shall we find the answer?" And, if pupils are really to grow in ability to solve problems, they must be encouraged to experiment, observe, read, discuss, look at pictures, inquire, and make use of all available resources for learning. Such activities as these are now performed in order to solve a problem.

Pupils may begin to search for experiments that will shed light on the problems. They may originate experiments for the same purpose. Each experiment is performed so that data may be gathered to apply toward the solution of the problem. Pupils will soon see that it is not possible to learn everything from experimenting. Relying entirely upon experimentation would necessitate jumping to conclusions. They must consult authorities. They must check their findings against what others have discovered. This constitutes the real reason for using the text and supplementary materials.

When it becomes necessary for pupils to study objects or processes not present in their environment, they may use slides, motion

pictures, and other visual aids that will help verify or disprove their findings. The method of science constantly cautions the learner to hold conclusions tentative, collect more data, and verify the findings. The method of teaching then becomes a scientific method, simulating on a small scale the method used by scientists.

Many avenues of learning are necessary if the method of instruction is to lead pupils toward the goals of instruction. Science teaching cannot be a reading course and achieve the objectives assigned to it as part of the total curriculum. Neither can it be confused with useless construction of models and painting of murals. Each activity must have focus: the attainment of the objectives.

THE SEQUENCE OF LEARNING

Effective science-teaching must be actively concerned with helping pupils develop a logical sequence of ideas as they proceed through the elementary school. The teaching method must make it possible for pupils to build on their previously acquired knowledge, to put together their learning experiences, and to make increasingly complex generalizations.

The method of instruction should be so designed that pupils are challenged at each new level of their program. As their ability to see relationship increases, so should the expectation of instruction. Unless pupils are challenged to extend themselves as they proceed, it is unlikely that they will achieve the objectives of the science programs.

In the elementary school we need continually to remind ourselves that good methods of instruction in science are similar to good methods of instruction in other areas of the curriculum.

The Teaching-Learning Situation

THE TEACHER

Any discussion of a good classroom teaching-learning situation may logically begin with an appraisal of the teacher and of his role. There is scarcely anything wrong with the science education in our schools today that some skilful science-teaching cannot cure. The improvement begins with the assignment of a teacher who has a good science background, has a knowledge of the objectives for teaching science, is interested in teaching, knows how children learn, and *wants* to be a good teacher. The teacher, then, is the key

to the learning situation. His enthusiasm carries to the learner. His interests often become theirs. His concern for them is reflected in his success as a teacher.

The good teacher is a guide; but he is more than that. Because of his experience and understanding he not only guides but also directs the learning into profitable channels. He keeps learning from being a narrow experience by broadening the interests of the learner and by opening up new avenues of learning.

THE TOOLS

Without adequate tools, even the best teacher is handicapped. The room itself must be conducive to the learning that is expected of the pupils. The equipment and facilities needed to implement the curriculum should be available in the classroom. It is the curriculum that determines the equipment and apparatus that are needed. It sometimes appears that the reverse has been the case—materials are ordered and the course built to match them.

Good elementary-school science-teaching can be accomplished with a minimum of science equipment, provided it is appropriate to the age and background of the children. It should be simple in construction, useful in helping pupils understand science ideas, and safe to handle. It may be homemade, but, if the making of the apparatus does not contribute to learning, the time used in making it is misspent. In addition to the simple handmade apparatus, elementary pupils should also have access to precision instruments and scientifically certified materials. Handmade barometers, for example, may be useful in understanding the scientific principles involved, but a real barometer should also be available to help pupils become acquainted with the more accurate methods of gathering data. It is desirable that at least the less-expensive kinds of material be available in sufficient quantity to make small-group experimenting possible.

If we intend to encourage teachers and pupils to make some of their own learning materials, adequate tools and raw materials must be provided. Also, some workbench space in the room or in some other convenient place is essential.

Generally speaking, elementary-school science is taught in the self-contained classroom. For the most part, such rooms serve adequately when they have running water, electrical outlets, facilities

for the use of audio-visual materials, bulletin boards, and storage space.

Easily accessible library facilities are essential for good classroom instruction. In addition to basic textbooks, many supplementary science books are needed for good teaching in science. These reference and additional-reading sources should be selected to enrich the curriculum and should be of a variety of reading levels.

CLASS SIZE

Good science-teaching cannot go on in classes that are too large for group work. Individualized instruction cannot be expected when classes are too large. There must be space, time, and opportunity for pupils to handle materials and do some investigating individually and in small groups. Unless provision can be made for pupil participation, it is hardly likely that all the objectives of science instruction can be achieved. When teachers are obliged to handle classes larger than 25 or 30 pupils, science often becomes a reading, watching, and listening experience. There is little discovery, manipulation or individual participation. There can be little provision for special attention to unusually talented pupils or for helping those who need special attention because of their more or less limited capacity.

Characteristics of Good Science-Learning Activity

The impact of the activity movement in education is now legend. The movement is described in considerable detail in an earlier yearbook.[1] Science activity begins at birth when the child first interacts with his physical environment. In his early development his behavior is that of orientation to his surroundings. His inquisitiveness leads him to test his world in a variety of ways.

The elements which comprise a good science-learning activity are not unlike the elements of a good learning activity in other areas. However, there are some aspects of a science activity which are peculiar to science. Just as science, as a tool of learning, has a unique contribution to make to the educative process, so do science activities make a contribution toward helping children gain in power and in maturity. As has been indicated, problem-solving is essential to

1. *The Activity Movement.* Thirty-third Yearbook of the National Society for the Study of Education, Part II. Chicago: Distributed by University of Chicago Press, 1934.

effective learning in science; the activity is the vehicle which provides the means for the solution to the problem.

VARIETY OF ACTIVITIES

In a learning situation, the child carries on activities which help him internalize experience and gain basic understandings commensurate with his needs, abilities, and interests. Certain situations may require different types of activity. Some activities are more effective than others for individuals of different needs and interests. A wide variety of activities should be planned in order to adequately take into account the differences among individuals. Since interest and need are inextricably tied up with children's day-to-day experiences, it is important that activities have both meaning and significance to them if they are to achieve the goals that are sought through problems and developmental tasks.

Variety in the plan of organization of activities is also desirable. In some instances children may, with profit, work together in a certain general area but, within that area, may also pursue their individual interest. For example, if the main area of concern is the International Geophysical Year, interests in rocketry, satellites, orbits, oceans, and antarctica would naturally arise, and appropriate activities would follow accordingly. Some youngsters might engage in an activity in a related area such as "weather at the South Pole" and remain within the broad organizational plan. Activities may, of course, be of varying length and importance.

ACTIVITIES AND DIRECT EXPERIENCE

Whenever possible, children should be given opportunity to gain knowledge of the world about them through direct experience. When children engage in activity in which they gain firsthand knowledge for a purpose, clear understanding and intelligent interpretation of the environment are likely. When activities are related to the life experience of boys and girls, it is more likely that the learning will have greater application to daily living.

Adequate Planning for Science-Teaching

As has been pointed out, the objectives in science can be achieved in many different settings. The structural organization of science

education, science as a separate subject or combined with other areas of learning, is significant but not nearly as important as what the teacher and his pupils do daily in the classroom.

PLANNING FOR OVER-ALL GUIDES

A single science-curriculum guide for all children in all places would be most undesirable, and yet there are objectives in education which are generally accepted. In planning, it is important that the teacher hold to these objectives and provide experiences through which children can achieve the objectives. This transition from objective to experience is no easy task for curriculum-makers, but it is of fundamental importance.

A school staff in planning will often involve leaders in a community, representing a cross section of professions and interests. These leaders may help in determining the general objectives of education, including science education. The school staff, however, is responsible for stating these objectives in behavioral terms and for drawing up plans for making children's experiences lead to the attainment of these objectives.

ALL TEACHERS PLAN TOGETHER

The basic elements of design in this plan are scope and sequence. *Scope* refers to content, methods, activities—both horizontal and vertical experiences within the science program. It is sometimes referred to as the "what" of the curriculum. *Sequence* refers to the arrangement of experiences—the continuum, which is provided throughout a child's school life. It is sometimes referred to as the "when" of the curriculum.

The greater the number of teachers that become involved in building the design of the program and that feel a part of it, the more successful will be its implementation. One means of involving large numbers of teachers is through the use of committees composed of classroom teachers and other personnel. Such representation may cross grade-level lines and attendance-area boundaries. City-wide groups may work closely with individual school committees which plan ways and means of implementing science programs in the classroom. The smaller committees may be involved in exploring resources—facilities, materials, aids, and equipment—and in an all-

inclusive in-service education program. It is sometimes expedient to develop grade-level committees to carry on similar functions but with focus on grade-level needs. Procedures will vary with the size of the school involved and with the type of provision made for curriculum development.

PLANNING FOR BALANCE AND FLEXIBILITY

There is disagreement among many conscientious teachers regarding the nature and amount of content. These are determined in large measure by the teacher's individual interest and competency, administrative pressure, compulsory pupil achievement (mainly in reading in the lower grades), and environmental conditions. These factors, occurring singly or in combination, make a difference in what is taught.

The teaching staff through committee organization usually determines the scope and arranges the sequence of learning experiences for each grade. The staff is generally aware of the wide range of capacities, interests, and needs of children within each grade. Different rates of maturation of children make it necessary to keep the framework flexible and broad. Individual differences of children and teachers and unforeseen happenings occurring from day to day make flexibility of the curriculum essential.

In many planned programs, time is allocated for science-teaching. The amount varies from place to place. In many large school systems three 40-minute periods a week are standard. In other systems, mainly in self-contained classrooms, the teacher relates science to other areas of the curriculum with no definite time allocation. Skill, or lack of it, on the part of the teacher determines the effectiveness of this approach. Some teachers in self-contained classrooms set aside a block of time amounting to as much as 100 minutes per week for science. There is great variation in the amount and distribution of time allocated to science, but it is essential that time be allocated, otherwise little science will be taught.

TEACHER-PUPIL PLANNING

Teacher-pupil planning cannot be structured in advance. The planning and selection of activities should take into account the composition of the group, the competency of the teacher, and na-

ture of the learning that is in progress. Encouraging pupil participation in decision-making, planning, and evaluation will make the activity more purposeful and the attainment of desired goals more probable. The teacher guides and directs the pupils in the joint planning sessions.

The extent to which science is taught in the classroom is related in great measure to the degree to which science experience is valued by the teachers and the pupils. The amount taught tends to be large when the significance of science in our culture and its role in education are generally understood.

Evaluation as a Part of the Teaching-Learning Process

Evaluation should be considered an integral part of the total teaching-learning process, and it should be continuous. The assessment of the effectiveness of teaching is a day-by-day, perhaps even an hour-by-hour, procedure. The results of evaluation supply the impetus for the redirection of the teaching-learning process with all that this implies. The evaluation process will lead to the examination of previously accepted goals, of methods being used by teacher and learner in moving toward these goals, and of the merits of the very evaluation procedures themselves.

It seems apparent, then, that evaluation is a continuing part of teaching and learning and is directed toward the appraisal of the quality of the teaching-learning process. However, in order to assess quality, each teacher must have an awareness of the desired outcomes of teaching. True evaluation of teaching occurs only when that evaluation is in terms of the accepted goals of teaching in a particular institution.

It is not enough to evaluate in terms of only one goal, such as the retention of facts. Evaluation should be in terms of *all* of the goals that are set for the teaching process.

Our primary concern in evaluation is to determine the nature of the changes in behavior that have taken place. It is not enough for the pupil to be able to *recite* facts. Facts should make a difference in behavior. Children's science experiences should influence their patterns of thinking and acting. In evaluation we try to determine whether or not the pupils' science experiences have influenced their thinking and how teaching can be further improved. Perhaps an

example which shows the dangers of limited, narrow evaluations will point up the importance of evaluating in terms of all goals and in terms of changes in behavior.

Late in April, the teacher of a group of ten-year-olds in a consolidated school was deluged with bouquets of wild flowers, gifts of the children. This fitted into the teacher's plan to teach the names of ten wild flowers common to the state. It was easy to arouse interest in the lesson, as specimens of seven of the flowers were in the room. There were even enough of five of the varieties of flowers for each child to press his own specimen, mount it in a booklet, and write the name of the flower beneath it. In the next few days, enough specimens of two rarer wild flowers were gathered by the eager children so that each child could also have a specimen of those flowers for his book. Specimens of the remaining three wild flowers on the list were discovered, and each of the finders graciously shared his spoils with his best friends. Those children not so fortunate as to have a specimen of these three rarer flowers drew a picture of each of them. So each individual booklet was complete with specimens or sketches of the ten wild flowers in question. Furthermore, on a test which required the children to name the ten common wild flowers, almost every child was successful. Those who were unsuccessful were retaught. On another test, the children showed they could do even more. They were able to match pictures of the flowers with the proper names, showing that they were not only capable of naming the flowers but also of identifying them. The teacher was proud of the results of the test because one of the goals had been to learn the names of the flowers. This goal had been surpassed, for most of the children were able to identify the flowers. In terms of the *one* goal, this traditional teaching-learning process had been eminently successful.

A more significant goal, however, might have been to develop an intelligent attitude toward conservation of natural resources. In terms of this goal, the teaching was not very successful. In their collections, the children had several specimens of hepatica, bluebell, redbud, and trailing arbutus which were on the "protected" list of the state. If this teacher had evaluated his program in terms of conservation behavior as well as of the retention of facts, he would have

changed his approach to teaching and developed much more significant experiences.

As a result of such an evaluation, the teacher might be prompted to begin the project before the first spring flowers appeared. Pictures of the flowers might be put on the bulletin board so that children would be alerted to watch for these flowers and to report their observations in class. Trips to observe and study the flowers in their natural habitat might be arranged. Under sensitive and insightful handling, not one of these wild flowers would be picked. Evaluation would be concerned with behavior and attitudes relating to conservation. The children would learn to recognize certain flowers and to enjoy them. In addition, they would learn a great deal about the natural habitat of these wild flowers and how and why some are protected. Evaluation in terms of all of our goals and in terms of desired behavior can lead to desirable and effective science experiences.

Some teachers find it difficult to evaluate in terms of such a goal as conservation behavior. Yet, this is an important goal to keep in mind. It is a goal toward which teachers may direct the learning process continuously throughout the year. If this is the case, constant evaluation of the growth of individuals toward this goal is in order. As children meet new situations calling for conservation practices, are they encouraged and helped to examine their behavior in order to change their patterns of behavior if change seems to be desirable?

If the goal of elementary-science teaching is to effect differences in the lives of children, evaluation of that process must be focused on behavior. This is difficult, but it is not impossible; it is time-consuming but rewarding.

TEACHERS EVALUATE PUPIL GROWTH IN SCIENCE

An important method of judging the effectiveness of the teaching process is to appraise the growth of individual children. Such an appraisal requires constant attention to the progress and growth of the child toward stated science goals. If such goals as improved scientific attitudes, behavior consistent with the best of scientific knowledge, and improved ability to think through a question critically are held to be important, it then becomes necessary to assess a child's growth frequently and in action.

A number of techniques have been developed which are useful in

making an appraisal. The cumulative science record of the pupil is basic to the week-by-week and year-by-year analysis of individual progress. Such a cumulative record, kept by the school, may contain examples of a child's work, but, even more important, it contains teachers' analyses of progress based upon observation as well as upon other evidence.

Research workers have developed a number of effective techniques for obtaining information that is useful for evaluation. The following are some of these techniques:

a) Recording anecdotes which reveal progress or lack of progress toward such goals as improved critical thinking and skill in problem-solving. Navarra, in his study of concept-development in a child,[2] developed and refined useful techniques for observing children. A teacher selects a few children each week and concentrates on observing and recording the behavior of these children. In the course of a month or six weeks, he gathers considerable evidence of value in assessing the growth of individual children.

b) Using a tape recorder during discussion periods in science. Schenke found tape recordings of children's discussions a valuable tool in studying sources of children's science information.[3] This technique merits wider use than it now has. Tapes made at intervals of several weeks are analyzed by the teacher in order to ascertain progress of individual children. In addition, they are used by the children, especially those in the upper grades, in assessing their own progress from time to time.

c) Recording on a check sheet the types of contributions that individuals are making. West and Hill developed check sheets for recording the observation of children's contributions.[4, 5] The use of a check sheet with entries for indicating a child's request for information, contribution of fact, suggestion for solving a problem, remark indicating skepticism, or statement revealing reservation of judgment makes it possible for the busy teacher to record the information. As a child makes a remark which fits one of the categories, his initials are entered in the proper category. Records made during several con-

2. John Gabriel Navarra, *The Development of Scientific Concepts in a Child.* New York: Bureau of Publication, Teachers College, Columbia University, 1955.

3. Lahron Schenke, "Information Sources Children Use," *Science Education,* XL (April, 1956), 232–37.

4. Joe Young West, *A Technique for Appraising Certain Observable Behavior of Children in Science in Elementary Schools.* New York: Bureau of Publications, Teachers College, Columbia University, 1937.

5. Katherine E. Hill, *Children's Contributions in Science Discussions.* New York: Bureau of Publications, Teachers College, Columbia University, 1947.

secutive science discussions give a picture of the nature of the contributions of individuals.

After such data have been secured, it is necessary to evaluate critically the individual's growth toward specific goals. As an outcome of such an evaluation, a teacher may see the wisdom of changing his teaching process so that it will be more effective in stimulating and encouraging individual growth toward the desired goals.

Other techniques may also be used in examining pupil-growth progress. Some of these are as follows:

a) Analysis of the growth in concept formation of children as revealed through paintings, models, demonstrations, writings, or dramatizations. Garone used anecdotal words, tape recordings, and products of children's writings in his study of growth in science by children in a sixth grade. He found the products of children's writings especially useful.[6] Again, this must be an ongoing process if it is to be fruitful.

b) Use of essays or paper-and-pencil tests before and after an area of science knowledge is explored in order to ascertain progress in terms of acquisition of facts.

c) Assignment of a problem requiring the use of materials for its solution, such as "What are some good conductors of electricity?" and then observing the manner in which a child moves toward the solution of the problem. Stern used this general approach in his study of concept formation among children.[7] Boyer used a similar approach in evaluating student achievement.[8]

d) Assignment of a problem requiring the use of a source book, a field guide, or resource person for the acquisition of data and then observing the manner in which a child gathers and uses the data.

e) Assessment of the progress of a child in such skills as reading and understanding science literature, following written directions for a science demonstration, taking pertinent notes on science material, reporting findings clearly and accurately, verbally and in writing.

The procedures that have been listed are ways of obtaining the data for evaluation. The data must be analyzed to determine their meaning and studied to determine their value. To *evaluate* means to

6. John Garone, "Acquiring Knowledge and Attaining Understanding of Children's Scientific Concept Development." Unpublished Doctoral Project, Teachers College, Columbia University, 1958.

7. Aaron Stern, "Children's Explanations of Physical Phenomena." Unpublished Doctoral dissertation, Teachers College, Columbia University, 1951.

8. Donald Allen Boyer, "A Comparative Study of the Science Achievement of Pupils in Elementary Schools," *Science Education*, XXXIX (February, 1955), 3–12.

determine value; the teacher has to determine the value of the skills, test scores, examples of writing, contributions to discussions, leadership on field trips, construction of projects, and ability to read and assimilate science materials. Again, the teacher uses the goals of teaching as a guide in making this analysis and evaluation.

TEACHERS EXAMINE THEIR TEACHING

In addition to evaluating pupil progress, the teacher should examine critically his approach to the teaching of elementary science. This is especially important since many teachers of elementary-school children have not been adequately prepared to teach science by their preservice training. Therefore, it might be well for each classroom teacher, each consultant, and each administrator responsible for curriculum development to ask himself such questions as the following:

a) In my teaching and in my professional studies am I concerned with the importance of science to society and of the layman's responsibility in relation to the progress and use of science?

b) Am I constantly reading, televiewing, listening, or evaluating to enlarge my store of science content?

c) Am I making science an important part of my curriculum by planning and providing sufficient time and adequate materials for it in the program? Am I emphasizing it in reporting to parents?

d) Am I becoming more confident in approaching new problems in science and learning with the children?

e) Do I make flexible, but careful, plans for science?

f) Do I scrutinize my teaching constantly to determine whether or not my goals are desirable and attainable?

g) Am I aware of the progress or lack of progress of individual children?

h) Do I consult with colleagues in an ongoing appraisal of the total program in elementary science?

In evaluating the teaching process in relation to elementary science, consideration must be given to the degree of success attained in setting workable and reasonable goals, the use of techniques for appraising the progress of each child toward these goals, the constant self-appraisal by each teacher of his own attitudes and methods in the area of elementary science, and the ongoing evalution of the process of evaluation itself.

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CHAPTER IX

Improving Secondary-School Science

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in collaboration with

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Introduction

If, as it has been said, it takes fifty years for educational theory to become practice in the schools, science-teaching in the secondary schools of America is entering the most critical years of its history. Periodically since 1920 authoritative pronouncements[1] have been made regarding the purposes of science and the ways in which it should be taught in order to achieve those purposes. A comparison of the earlier statements of purpose with those set forth in chapter ii of this yearbook reveals marked similarity. For almost forty years there has been general agreement, in theory at least, regarding the purposes of science teaching. However, studies by Beauchamp[2] and Obourn[3] reveal that little has been done in science classrooms across the country to attain some of the most important of these purposes.

In many respects the gap between theory and practice in secondary-school science is still wide. For all these many years the theory

1. *Reorganization of Science* (U. S. Bureau of Education, Bulletin 1920, No. 26. Washington: Government Printing Office, 1920); *Program for Teaching Science* (Thirty-first yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by University of Chicago Press, 1932); Progressive Education Association, *Science in General Education* (New York: Appleton-Century-Crofts, Inc., 1938); *Science Education in American Schools* (Forty-sixth Yearbook of the National Society for the Study of Education, Part I. Chicago: Distributed by University of Chicago Press, 1947).

2. Wilbur L. Beauchamp, *Instruction in Science*. U.S. Office of Education, Bulletin 1932, No. 17, Monograph No. 22. Washington: Government Printing Office, 1932.

3. Ellsworth S. Obourn, "*Assumptions in Ninth-grade General Science.*" Unpublished Doctor's dissertation, New York University, 1950.

of science education has dictated that instruction in science should change the behavior of the learner in specified ways. Among other things, he should be more willing to base his decisions on reliable evidence. He should suspend judgment until he has pertinent evidence. The theory of science education has further dictated that to learn the content of science there must be an understanding of the generalized concepts or principles. Verbalization of scientific facts does not constitute understanding in science. Nor does superficial verbalization of science facts as a learning outcome have permanence. Learning studies have shown that exposure to science does not achieve these behaviors and understandings.

Although a large proportion of the citizens in our society have been exposed to science in the schools, the scientific illiteracy of the public mind is appalling. The products of science-teaching, as represented by the average citizen, are indeed disappointing. Science education in the future must break through to the behavior patterns of the "man in the street." To achieve desirable changes in behavior, science teachers must consciously direct young people in learning experiences involving the methods and attitudes of science. Furthermore, the facts and generalized concepts of science should also become means toward the development of desirable behavior patterns rather than ends in themselves. These commitments represent a major challenge in science-teaching today.

In the heat of present concern about the improvement of secondary-school science, there have been numerous proposals to manipulate present courses, to introduce new courses, and to rearrange the sequences of courses. It is imperative that these proposals be evaluated in light of a clearer comprehension of the purposes of science-teaching and a clearer insight into the nature of learning experiences by which young people can reasonably be expected to attain these purposes.

Forces Acting upon Secondary-School Science

There has probably never been a time when science in the secondary schools was completely autonomous. However, there have been times when it was more independent of pressures than today.

Practically from the beginning of science instruction in the secondary schools, colleges have exercised an influence upon what sci-

ence was taught and, to a lesser extent, on how it was taught. Even though the colleges considered certain of the science courses as college preparatory, the colleges in turn taught their Freshmen students as though they had had no previous science. A number of early studies have shown that students who had had high-school chemistry did no better in college than those who had had no high-school chemistry.[4]

There have been several major efforts to bring about changes in secondary-school science.[5] These efforts were advanced by a relatively few forward-looking educators in a more passive social climate than exists today. It is extremely doubtful that the initial impact of these efforts has had any marked long-term effect upon secondary-school science.

Times have changed. Today there are many new forces acting upon secondary-school science. No longer are the requirements for college entrance and the theory of educators the only forces with which curriculum-planners in secondary-school science must contend.

THE CITIZEN'S INTEREST IN SCIENCE EDUCATION

In America the public schools belong to the people. Through their elected representatives they define the policies by which schools shall be organized and managed. They also determine the facilities that will be provided to carry on the program. Within the past ten years citizens have become increasingly interested in and concerned about their schools. Through the organization of citizen committees they have become more articulate about their concerns and more effective in initiating action. In situations such as these, school administrators and teachers have often found themselves in a rather indefinite professional-laymen relationship.

The national concern about the improvement of science-teaching in the secondary schools has become quite properly the concern of

4. Victor A. Noll, "The Results of Certain Experiments in the Teaching of Chemistry to College Students," *Journal of Chemical Education*, VI (October, 1929), 1740–47.

5. Samuel R. Powers, "The Work of the Bureau of Educational Research in Science," *School Science and Mathematics*, XLI (January, 1941), 7–9; Wilford M. Aikin, *The Story of the Eight-Year Study* (New York: Harper & Bros., 1942).

many local citizen groups. In some communities, uninformed citizen groups have brought ill-advised pressures upon the schools with such slogans as, "Let's go back to the good old days." However, in many communities they are asking searching questions about the nature and quality of science instruction in their elementary and secondary schools. They want to be told the purposes of the science program in a language which they can understand. They want to know how science learnings at each successive school year build on the previous year. They want to know what provisions are being made for individual differences among students, including the gifted. They want to know what additional facilities are needed in order to do a better job. In many schools questions such as these represent a very real challenge to science teachers who have not themselves worked out satisfactory answers. To some science teachers, citizens' questions represent a real threat to their security.

The time has passed when the science teacher's only contact with the parent-citizen is the annual open-house where he tells them about the science program. Wherever possible, competent citizens should be encouraged to work on science advisory committees, recognizing the fact that the development of the curriculum is the school's responsibility. As specialists in the teaching of science, science teachers must provide professional leadership in working with these committees. If this is done, the work of citizens' committees can become one effective means of building science programs that will have community support.

EMERGENCE OF ELEMENTARY SCIENCE

The case for elementary science has been set forth in chapters vii and viii of this yearbook. It is quite clear that elementary schools across the country will be developing stronger science programs in the years ahead. Much of the science that was formerly taught in the junior high school will now be taught in the elementary school. This fact constitutes a second force pushing with increasing pressure upon the science program of the junior high school. To ignore this by failing to take immediate steps to plan a developmental sequence in science beyond the sixth grade will seriously limit the effectiveness of the secondary-school science program.

REPORTS OF PROMINENT COMMITTEES AND INDIVIDUALS

Within the past five years, numerous committees have issued reports on the teaching of science in the secondary school.[6] Symposia and conferences have been conducted and detailed in published reports.[7] Individuals of national prominence have also set forth their recommendations where all may read.[8] Some of these statements are based upon analytical study of the problems and thoughtful deliberation about courses of action. Others appear to be off-the-cuff personal opinions. Regardless of their varying quality, these reports have operated as a third force impinging upon secondary-school science.

A few of the reports have included recommendations regarding science sequences in the junior and senior high school for all young people. Some have also made recommendations regarding courses for those who have science talent as well as those who shy away from science. However, most of these reports have dealt with only one level of the curriculum rather than the total science curriculum. Few of them have considered the elementary school and the junior high school as contributing to the total science program.

SCIENTISTS AS CURRICULUM BUILDERS

For the past twenty-five or thirty years science curriculum materials, such as courses of study, textbooks, and the like, have generally been written by secondary-school science teachers and science educators in the colleges and universities. However, within the past few years scientists in greater numbers than ever before have become concerned about the secondary-school science curriculum. Through their professional societies, their participation in the various science-

6. *Bulletin of the National Association of Secondary-School Principals*, XLII (September 1958), 10–12; *Improving Science Programs in Illinois Schools*, pp. 52–55 (edited by William O. Stanley. Urbana: University of Illinois, 1958); National Science Teachers Association, *Science in the Junior High School* (Washington: National Education Association, 1959).

7. *The High School in a New Era* (edited by Francis S. Chase and Harold A. Anderson. Chicago: University of Chicago Press, 1958); *Mathematics and Science Education in the U.S. Public Schools* (U.S. Office of Education, Circular No. 533. Washington: Government Printing Office, 1958).

8. James B. Conant, *The American High School Today* (New York: McGraw-Hill Book Co., 1959); Hyman George Rickover, *Education and Freedom* (New York: E. P. Dutton & Co., 1959).

education activities of the National Science Foundation, and the universities and colleges with which many of them are associated, they have become involved in curriculum development. The three most notable examples of this are: (*a*) the new high-school physics course developed by the Physical Science Study Committee; (*b*) the high-school chemistry course on film developed with the assistance of an advisory committee of the American Chemical Society; and (*c*) the new high-school biology course being developed by the American Institute of Biological Sciences. Although high-school science teachers and science educators have assisted with the development of these courses, the scientists have played a major role in defining the purposes of the courses and the organization within which they will be developed.

Some have felt that the scientist is too far removed from the problems of teaching high-school youth to be effective in planning courses. It is now quite evident that, to bring about the needed reorganization and revitalization of science courses in the secondary schools, co-operation of the scientist will continue to be necessary. In the past, curriculum revisions in science have been made so slowly that changes from year to year have been almost imperceptible. The physics course of the Physical Science Study Committee, by comparison, has been a revolutionary development.

Science Courses and Sequences

There are great differences among secondary schools in the United States. They differ in size, in organization, in the kind of facilities they have, and in the competence of their teachers. More than half of the public high schools in the United States enrol fewer than two hundred students. A high school with an enrolment of two hundred presents quite different problems from a school five or ten times that size. For obvious reasons, the possibility of the smaller school offering a high-quality science program is not as good, and yet size alone is not the ultimate determiner of quality.

Proposals have been made for the development of regional high schools in sparsely settled parts of the country.[9] Other proposals for informal co-operative use of special services, facilities, and profes-

9. Conant, *op. cit.*

sional personnel by two or more small schools have been made.[10] It will probably be a long time, if ever, before the wide variations among secondary schools will be reduced to any great extent. This fact complicates the problem of making blanket recommendations in science education for all secondary schools.

As has been pointed out in the earlier chapters of this yearbook, society can no longer permit its schools to ignore individual differences of students. The importance of each student being educated to the maximum of his ability has significance beyond its being an individual right in a democracy. Its realization is essential for the survival of our democracy. This is especially pertinent in science. Furthermore, it applies to students at all intellectual levels—not only the academically talented but the others as well. To plan science courses and to offer them in appropriate sequences so that all may benefit to the maximum of their respective abilities is indeed a most challenging assignment. From a "realistic" point of view, the assignment would seem impossible. From a professional point of view, however, this is a goal toward which all efforts in building science curriculums for the secondary schools should be directed.

SCIENCE FOR GRADES VII AND VIII

Science for Grades VII and VIII should be general science in the sense that it, like elementary science, should draw upon all the sciences for its content. Its organization, however, should relate to the broad areas of human activity in which the selected content and methods of science play important roles.

In school systems that have well-organized elementary-science programs, the seventh- and eighth-grade science courses should build upon the elementary program in a clearly defined sequence. Whereas much of the science content in the elementary school is descriptive, the content in Grades VII and VIII should be less descriptive and more interpretative. Wherever appropriate, theoretical interpretations should be developed.

Definitive research regarding the nature of science concepts that can be learned by pupils at each grade level is lacking. There is evidence, however, that the background of experience of the learner is a primary factor in determining his capacity to conceptualize in

10. Merle R. Sumption, "What about the Small High School?" *NEA Journal*, XLVIII (March, 1959), 55–56.

science.[11] With pupils coming from the lower elementary school into Grades VII and VIII with more experience in science, it is reasonable to expect them to be able to work with concepts heretofore considered beyond the comprehension of the average seventh- and eighth-grade pupils.

Hill's study[12] also revealed wide variation at any one grade level in the ability of individual pupils to conceptualize. Even though all seventh-grade pupils may have pursued relatively the same science program from kindergarten through Grade VI, one cannot assume that they have all reached the same level. In fact, the better the science program in the elementary school, the greater the variation in achievement will be by the time pupils reach the seventh grade. This has a number of important connotations for the development of science courses for Grades VII and VIII.

Seventh- and eighth-grade pupils should have special science teachers who have good science backgrounds. Although the science to be taught may appear to be elementary, the problems of adapting the learning experiences to a wide range of abilities and interests requires the efforts of a highly resourceful teacher, especially one who is resourceful in the various sciences. The reported "damping off" of science interests of pupils after the sixth or seventh grade is accounted for in part by the fact that science beyond these levels is too frequently taught by teachers poorly prepared in science. Because of the critical nature of these grades, teachers with the very best preparation should be teaching seventh- and eighth-grade science.

Seventh- and eighth-grade science courses should provide for a wider range of learning experiences than is generally possible in the elementary school. Greater provision should be made for laboratory work of a problem-solving nature. Brandwein[13] has shown that pupils taking general science taught in a perfunctory way, with little or no laboratory work, elect fewer science courses later. Smith[14] has shown how laboratory experiences in general science can be used in

11. Katherine E. Hill, *Children's Contributions in Science Discussions*. New York: Bureau of Publications, Teachers College, Columbia University, 1947.

12. *Ibid.*

13. Paul F. Brandwein, *The Gifted Child as Future Scientist*, p. 74. New York: Harcourt, Brace & Co., 1955.

14. Herbert F. Smith, "A Determination of Principles and Experiments Desirable for a Course in General Science at the Junior High School Level." Doctor's dissertation, University of Michigan, 1951.

developing understanding of selected science principles. If the span from elementary-school science to senior high school science is to be bridged in a developmental sense, laboratory work must become a common experience in seventh- and eighth-grade science. Facilities must be provided.

Although the seventh- and eighth-grade science courses must be clearly organized to insure appropriate scope and effective sequence, they should be reasonably flexible. The courses should be flexible in the sense that the teacher should be free to reduce, extend, or supplement them whenever and wherever such adaptations seem appropriate in order to meet more nearly the needs and abilities of his pupils.

The amount of time per week scheduled for science in Grades VII and VIII should be determined in light of the total curriculum offerings. As much, but no more, time should be scheduled for science as is scheduled for such courses as social studies and English. In order to provide for problem-solving laboratory work in science, however, it is desirable that science be scheduled for a minimum of one hour for each class session. Where periods are shorter than one hour, science classes should be scheduled for one or more double periods a week.

SCIENCE IN THE NINTH GRADE

General science was introduced into the schools as a ninth-grade subject. Since that time, however, much of its content and activities have been drawn upon to develop science courses in the first eight grades. In schools that have a well-developed science program through the eighth grade, the conventional ninth-grade general science is not adequate. Too often it is a repetition of the content previously covered. Many of the learning activities are also repeated.

General Science. At least three different kinds of science courses are appropriate at the ninth-grade level. In schools where there has been comparatively little science in the elementary school, a general-science course at the ninth grade would be desirable. The course should draw upon content from all sciences whenever appropriate. It should not, however, be a survey of science in the sense that it will touch many science topics lightly. It should more properly be an orientation to science. The course should be organized around a

relatively few unifying areas, selected in terms of their pertinence to the problems facing man today to which both the methods and content of science apply. It should be organized to show the interrelationship of the sciences, both conceptually and as they apply to our technological advancement. It should be a laboratory course that provides experiences in the methods of science. It should be conceptual rather than entirely descriptive.

A general-science course of the type described would also be appropriate in schools where young people come into the ninth grade with fairly good backgrounds in elementary science. It would be one of several science courses at the ninth-grade level from which pupils would elect.

Biological Science. Whenever possible, two other kinds of science courses should be offered at the ninth-grade level, general biological science and general physical science. The general biological science should be an adaptation of the present tenth-grade biology. Whereas most of the present high-school biology courses are descriptive surveys of biology, this course should be an orientation in the biological sciences. The orientation should be toward a better understanding of the methods of investigation that have been used effectively in the biological sciences; selected unifying concepts of life that man has developed by using these methods; and ways in which he has applied both methods and concepts to control living things.

General Physical Science. The generalized physical-science course should also be an orientation rather than a survey course. Its orientation should be toward the development of a better understanding of the methods of investigation that have been used effectively in the physical sciences; selected unifying concepts of matter and energy that man has developed by using these methods; and ways in which man has applied both methods and concepts to control matter and energy. Both the general biological science and the general physical science should be laboratory courses with a maximum of problem-solving experiences.

It would be desirable to make all three of these courses—general science, biological science, and physical science—available to ninth-grade pupils. In some schools this may be impossible. In such schools decisions regarding which one of the three will be offered will have to be made in terms of a number of factors such as: the nature of the

elementary-science program; the number and qualifications of science teachers; and the science program for tenth, eleventh, and twelfth grades.

SCIENCE IN GRADES X, XI, AND XII

The three science courses previously described for the ninth grade should also be available to those tenth-, eleventh-, and twelfth-grade pupils who desire or are advised to continue their study of science at a general rather than a specialized level. In schools where two years of high-school science are required for graduation, both a biological- and a physical-science course should be included. Where high schools provide a vocational-training curriculum, numerous applied- or technical-science courses may be offered in lieu of the general courses described earlier.

The door should never be closed to any reasonably capable high-school student who may want to study science in a specialized manner. By the time many young people reach the tenth grade they have made up their minds regarding their future academic plans. Conant[15] has recommended that the top 15 per cent of the high-school pupils be urged to elect a minimum academic program including three years of science. For the college-bound student, chemistry, physics, and advanced biology beginning with the ninth or tenth year would be desirable.

Chemistry and Physics. Efforts such as those of the Physical Science Study Committee that are being made to redesign high-school chemistry and physics are aimed at reducing the number of topics conventionally covered in these courses and concentrating upon the development of a better understanding of a few conceptual patterns which are fundamental in modern thinking regarding these fields.[16] Furthermore, the laboratory work for these new courses is more experimental and more directly oriented toward problem-solving than the conventional "cook-book" laboratory exercises. In these ways the new courses in chemistry and physics will more nearly achieve the objectives of science-teaching than the earlier courses. Because of the way in which it is recommended that these courses be taught,

15. Conant, *op. cit.*

16. David Vitrogan, *Modern High School Physics: A Recommended Course of Study.* Science Manpower Project Monographs. New York: Bureau of Publication, Teachers College, Columbia University, 1959.

they will be more meaningful and more challenging to that upper 15 per cent of the high-school population than the conventional courses have been.

Advanced Biology. The efforts to design a new high-school biology course are aimed at reorienting biology from a descriptive science to an experimental science in keeping with modern developments in biology. The extent to which the experimental approach in biology can be used effectively with high-school pupils before they have had chemistry and physics will have to be studied. It is quite evident that the fundamental concepts in modern biology are basically physical-chemical in nature. To pursue a study of them to any reasonable depth requires background in both physics and chemistry.

An advanced biology should be offered in high schools where possible. It would be elected by college-bound students who have an interest in pursuing science or allied careers. Since knowledgeable scientists are anticipating that the next great break-throughs in science will be in the biological sciences, it is extremely important that the embryonic scientists, now in the high school, have an opportunity to view biology as an advancing experimental science before they leave the high school.

The Talented in Science. How to accommodate the talented in science at the high-school level is still an unanswered question. With a few exceptions, not much attention had been given to the question prior to 1950. Recognition of our scientific manpower problem has initiated increased general concern about the problem. Many suggestions have been made and a number of trial-and-error attempts have been made to carry them out. Late in 1958 a work conference on providing for the able science student was held under the joint sponsorship of the Talented Student Project of the National Education Association and the Future Scientists of America Foundation of the National Science Teachers Association. The report of this conference[17] offers suggestions on the selection of content for courses for these students, methods of teaching such groups, and selection of teachers to work with the talented. As is pointed out in chapters iii and xvi of this yearbook, however, more definitive research is

17. *Science for the Academically Talented Student.* Washington: National Education Association, 1959.

needed on how the talented can be identified and on the factors which account for such talent. Studies of the relative effectiveness of different proposals for accommodating the talented in science in the high school are also needed.

To some it has appeared that the answer lies, in part, in bringing college courses in science down into the high school in order to enable students who take those courses to qualify for advanced standing in college. This plan for acceleration appears to be one whereby an attempt is made to fit the pupil into a pattern of established science courses. A sounder approach, psychologically, would be one which attempts to provide opportunities for enriched experiences in science to fit the needs of each of the talented as those needs are identified. Of course, this requires time and demands effort on the part of creative teachers who are already overworked. This is probably the major reason for the schools' failure to do more.

Teaching the Sciences

It is clear from what has been written in chapter ii that science has a number of purposes to achieve if it is to merit a place in the secondary-school curriculum. It should carry young people farther along in their understanding of selected generalized concepts, the methods of science, and the social implications of science. It should develop an appreciation of the role of science in advancing man's understanding and control of the world of nature. It should develop a disposition to use the knowledge and methods of science whenever appropriate. It should develop abilities that make young people increasingly independent investigators and learners. Finally, it should acquaint young people with career possibilities in science, including teaching.

Any science course which fails to provide young people a reasonable opportunity to achieve its major objectives is inadequate. The assumption that merely studying the content of science will concomitantly achieve these objectives has been shown from the cited research in chapter iii to be invalid.

These objectives must serve as the bases for selecting and organizing the content of the science course. They are the criteria by which teachers make decisions in planning and managing learning activities in the classroom and the laboratory. They should also serve as the criteria by which teachers evaluate the achievement of their pupils.

A review of the research in which the relative effectiveness of various methods of teaching science are compared leads to the conclusion that there is no one method of teaching science that can be considered unquestionably superior to all others.[18] Teachers differ, and so do the pupils they teach. Conditions under which teaching must be done varies from school to school. Pupils' readiness for learning varies from day to day and from one learning task to the next. These and the many other variables encountered by the teacher make his job an extremely difficult one. It means that the methods by which he works with young people should be permissive and flexible. The methods must encourage the active participation of the learner. It is through such involvement that effective learning takes place. By observing pupils as they become actively involved in the learning process, teachers find out about their learning idiosyncrasies. When methods of working with young people are flexible, provision can be made more effectively for these differences. To make these adaptations calls for expert teachers. Expertness of this kind should be one of the major goals in the education of science teachers. The goal should not be compromised because of the difficulty experienced in our efforts to achieve it.

As has been pointed out in chapter ii, it takes time to teach science for understanding. This means that, within the time limits presently available for teaching any one of the secondary-school science courses, it will not be possible to cover the large number of topics or problems generally included in these courses. More careful selection must be made. The selection in turn must be guided by the objectives to be achieved.

Articulation and Correlation

The commitment to a twelve-year science program is becoming a reality in many public schools. To design these programs so that they have reasonable sequential development has presented many problems. Although the problem has not been completely solved in the elementary school, progress has been made in a number of school systems. Less progress has been made in achieving a dependable articulation between the elementary and the secondary school.

18. J. Darrell Barnard, *What Research Says to the Teacher: Teaching High School Science*, pp. 12–17. Washington: National Education Association, 1956.

ARTICULATION

The problem of articulation is based upon the assumption that learning in science should be developmental from one level to the next. In terms of conceptual learning, it means that there should be development in both the breadth and depth of the learner's concepts in science. In terms of the development of learning skills and abilities, it means that the learner should become increasingly independent and self-directive in his learning.

Articulation in Terms of Concepts. Answers to the question of what concepts should be taught at each successive level must come from two principal sources: the frame of reference or point of view within which the science program is conceived, and the nature of the learner at each successive school level.

Numerous studies, such as those done by Martin[19] and Wise,[20] have been undertaken in an effort to define science principles. These lists constitute an important source of principles for curriculum-workers. The principles are arranged in rank order of their importance in general education as defined by the investigator's criteria. If curriculum-workers accept these criteria as valid ones, they have at their disposal a working list of principles. If curriculum-workers approach the problem of selecting concepts with other criteria in mind, then different lists or a reordering of the above lists would probably result. The point to be made here is that the selection of generalized concepts or principles, which form the basis of a twelve-year science program, is based upon value judgments. It is the responsibility of those who make the judgments to clearly define the value system, or educational point of view, out of which selections are made.

Little is known about the relative capacities of young people at different age levels to develop and use science concepts. Some studies have been done, but they are too limited in scope and too dated in time to be of great value in planning science programs for

19. Edgar W. Martin, "A Determination of the Principles of the Biological Sciences of Importance for General Education." Unpublished Doctor's dissertation, University of Michigan, 1944.

20. Harold E. Wise, "A Determination of the Relative Importance of Principles of Physical Science for General Education." Unpublished Doctor's dissertation, University of Michigan, 1944.

today's youth. Until there is more evidence on this problem, curriculum-planners will have to operate in the future, as they have in the past, pretty much by trial and error.

Articulation in Terms of Skills and Abilities. If the skills and abilities listed in chapter ii are valid objectives for teaching science, there should be progressive development of them from the kindergarten through Grade XII. As pupils proceed through the grades, they should become increasingly competent in such abilities as reading and interpreting science writings, performing suitable experiments for testing ideas, making valid inferences and predictions, and recognizing and evaluating assumptions. From studies[21] involving observation of classroom practices at the secondary level, it is evident that there is not progressive development of these abilities. There often appears to be a conflict between the educational point of view of the elementary school and the secondary school. In schools where this conflict exists, it will be extremely difficult to develop articulation in the science program between the two levels. There must be more effective communication between teachers, leading to clarification of educational views, from one level to the next before we can ever hope for effective articulation.

CORRELATION

The secondary-school science program should, where reasonable, be correlated with other secondary-school programs. Social studies, English, and mathematics are three programs in the secondary school with which it is reasonable to expect such correlation.

Social Studies. The Twenty-seventh Yearbook of the National Council for the Social Studies[22] makes it quite clear that the sciences and the social studies cannot be completely separated. Many suggestions concerning ways in which the two can be correlated are given. During the summer of 1958 a science-economics workshop was conducted under the joint sponsorship of the National Science Teachers Association, the National Council for the Social Studies, and the

21. Obourn, *op. cit.*

22. *Science and the Social Studies.* Edited by Howard H. Cummings. Twenty-seventh Yearbook of the National Council for the Social Studies, 1956–57. Washington: National Education Association, 1957.

Joint Council on Economic Education.[23] Thirty-three teams of teachers, each consisting of a science teacher and a social-studies teacher from each of thirty-three school districts, spent three weeks studying the impact of contemporary scientific and technological developments upon our economy. As an outcome of the workshop, it was hoped that social-studies teachers would incorporate new scientific developments wherever appropriate into their courses and that the science teachers would do likewise with new social and economic concepts. Co-operative endeavors of this kind are to be highly commended.

English. The importance of communication skills in science points clearly to the need for better correlation between science and English in the secondary school. There is evidence from the research[24] that the learning of both scientific knowledge and attitudes is enhanced by an extensive reading program. It is also clear that science teachers should assume greater responsibility for teaching effective reading skills.[25] When directors of research in one large research center were asked to list in rank order of importance the deficiencies of young scientists who become associated with their organization, the communications skills related to writing and speaking had top ranking on their list.[26]

Mathematics. Science teachers have always recognized the close relationship of science and mathematics. In many ways efforts have been made to correlate the two subjects. Recently, however, there have been a number of new movements for science-teaching at the secondary-school level.

It has been said that more new mathematics has been created dur-

23. *The Impact of Contemporary Scientific and Technological Developments upon the American Economy.* Proceedings of the Science-Social Studies Workshop. Edited by Haig Babian. New York: Joint Council on Economic Education, 1958; Charles Breedlove *et al.*, "A Science-Economics Workshop," *Science Teacher*, XXV (December, 1958), 451–52.

24. Francis D. Curtis, *Some Values Derived from Extensive Reading of General Science*, pp. 50–112. Teachers College Contributions to Education, No. 163. New York: Teachers College, Columbia University, 1924.

25. J. Darrell Barnard, "The Responsibilities of Science Teachers for Teaching Reading," *Improving Reading in the Junior High School.* U.S. Department of Health, Education, and Welfare, Office of Education, Bulletin 1957, No. 10. Washington: Superintendent of Documents, Government Printing Office, 1957.

26. "Qualifications for a Technical Career." Address by F. Senkowsky, Jr., Esso Research and Engineering Co., Linden, New Jersey, April 11, 1959.

ing the last fifty years than in the whole history of the human race. The gap between the mathematics traditionally taught in the secondary school and that recently fathomed by creative mathematicians has widened rapidly. If the gap had not been narrowed, the colleges and graduate schools would now find it impossible to educate adequately future scientists and mathematicians. Further, the applications of the new mathematics to both the social sciences and the physical sciences increased the urgency for a speed-up.

It became necessary to select from the vast collection of mathematical creations those which were most important for the current growing edges of the enterprise and for the applications of mathematics. Since time for education is limited, it was essential that obsolete topics be dropped in order to make place for the more valuable.

Teachers of college mathematics had felt for a long time that the secondary school did not develop in many students clear concepts and a competent grasp of mathematical proof. Therefore, they called for less emphasis on "routine manipulation" and "rote memorization" which seemed to characterize high-school algebra and geometry, respectively. To lessen the first weakness, more attention would have to be given to concept-development that terminated in precise definitions. More time would be given to analyzing the principles and postulates that characterized kinds of numbers and functions. There would be more emphasis on the structure of mathematics through such notions as set, group, and field.

With respect to proof, these college teachers wanted the students to have experience also with proof in simple number theory, algebra, trigonometry, and co-ordinate geometry. To provide the necessary time, it was recommended that less time be devoted to Euclid's plane geometry and that solid geometry be dropped as a separate subject and treated intuitively in connection with plane geometry. To sharpen and extend the notion of proof, material from logic would be integrated with the mathematics. The material suggested included the ideas of conjunction, disjunction, negation, and conditional implication, which are used in analyzing compound sentences, plus the concept of logical validity.

Some calculus would be taught in the twelfth grade in connection with the study of the polynomial, exponential, and circular functions. Several schools are currently teaching a one-term course in

probability and statistics produced by the Commission on Mathematics of the College Entrance Examination Board. At any rate, the students who have come through such a terminal program should be ready for a combined course in analytic geometry and calculus in their college Freshman year.

From this brief summary, the "new movements" seem to be in the direction of achieving better understanding of better mathematics for its own sake by more students. Apparently, the uses and applications of mathematics will be largely "played down." It is probable that only those students who are considerably above average in interest and ability will profit noticeably from the programs suggested. Nearly all of these will be looking to colleges for admission.

Apparently, the notions of science and mathematics for general education expressed by the Progressive Education Association in the 1940's are to be ignored to a large extent. It is doubtful that the average and below-average student would find a palatable educational diet in the new proposals. These "new movements" in mathematics are primarily for the special, superior group in mathematics; they are not likely to meet the needs of "all the children of all the people." For science-teaching in the secondary school these "new movements" mean only that special courses in science at the eleventh- and twelfth-grade levels can probably be given a more mathematical emphasis.

Summary

Never before has the concern about the improvement of secondary-school science been as widespread as it is today. This concern is shared by the educator, the scientist, and other informed citizens. In an effort to bring about action, numerous recommendations and movements have been initiated within the past ten years. In many local communities, citizen groups are asking questions about the science program and making recommendations to improve it. Through their national organization, secondary-school administrators have sought the assistance of science educators in the development of guidelines for the improvement of science programs in their schools. Impatient with the slow process by which science courses

have been changed to correspond more closely with modern scientific developments, scientists in co-operation with science teachers are working toward the development of some radically new approaches to the teaching of biology, chemistry, and physics in the secondary schools. In order to function professionally within the current ferment in science-teaching, science teachers must understand clearly the purposes for teaching science and the learning process as it relates to the attainment of the purposes.

CHAPTER X

Auxiliary Efforts To Improve the Secondary-School Science Program

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Public Interest in the School Science Program

The recent awakening of public interest in science and education has stimulated state and local school systems to reassess their science programs and has cultivated a growing interest in science-teaching on the part of groups not directly connected with the schools. Many agencies, both public and private, are focusing their attention on science, particularly at the secondary-school level. They have developed numerous and varied programs designed to stimulate improvement in science-teaching. Some of the programs have as their primary aim the identification and development of prospective scientists and engineers; others profess purposes which are broad and which have persisted for a long time. In most instances, however, the efforts are meant to supplement rather than replace the programs of local and state school systems.

It is the purpose of this chapter to analyze some of the significant efforts to develop programs for improving secondary-school science-teaching. An attempt has been made to describe the activities and proposals of various public and private groups, agencies, professional societies, philanthropic foundations, and colleges and universities. In some sections of this chapter, individual organizations have been included as representative of a group of such organizations. In no section is the listing of individual groups exhaustive.

Programs of Agencies of the Federal Government

Education in our nation is a function of the state. No provision was made for it in the federal constitution. Through the years, however, the federal government has assumed a small but increasing responsibility for it. The best-known examples of national concern are federal assistance to agricultural, technical, and vocational education and a number of programs established in times of war and depression.

Rapid development in fields of science and engineering in recent years has focused the attention of responsible persons and agencies upon science education. The seriousness of the situation has been intensified by the shortage of qualified science teachers and by the increasing enrolment in secondary schools, which promises to become much larger as the population of high-school age approximates the size that it will attain a few years hence.

The federal government has attempted, through many departments and agencies, to give aid to the teaching of science. At present a number of agencies are heavily involved in scientific and engineering activities through either the operation of programs or the support and purchase of services and products by contract, grants, or other financial arrangements. Agencies or their major constituent units that provide such aid include the Naval Research Laboratory, the National Bureau of Standards, the Public Health Service, the Atomic Energy Commission Laboratories and the Commission's Oak Ridge Institute of Nuclear Studies, the Agricultural Research Services, the National Science Foundation, the U.S. Office of Education, and the National Academy of Sciences—National Research Council (a quasi-governmental body). Altogether, some 39 federal departments and agencies have supported science activity of some kind.

The activities and programs described in the following paragraphs are necessarily brief and are representative rather than exhaustive.

In view of the nation-wide critical shortage of scientific and engineering manpower and the need for such manpower in expanding programs involving the national security, the President, in 1956, set up the National Committee for the Development of Scientists and Engineers. In addition, the President directed "all departments and agencies of the Government to co-operate fully with the work of

the National Committee and, at the same time, to re-evaluate and strengthen in every appropriate way their own activities which can contribute to the development and effective utilization of scientists and engineers."[1]

Many agencies had an active interest in the nature, extent, and aims of science instruction presented in the country's schools and colleges before 1956. Renewed and heightened interest and increased activity resulted from the President's directive.

As a result, a number of agencies have offered expanded opportunities to teachers and, in certain cases, to students: (*a*) to observe current research in laboratories directly operated by the agencies; (*b*) to participate in directly operated research programs of agencies; (*c*) to attend educational institutions to acquire added substantive background in scientific disciplines; (*d*) to conduct or participate in national programs involving the preparation of newer, more-effective science classroom instructional materials; (*e*) individually or in small groups to utilize scientific data resulting from scientific research, or otherwise develop materials for classroom use; and (*f*) to attend short, intensive science courses at federal installations.

In all instances the teacher is free to accept or reject any federally offered funds, services, and materials and to adapt the latter, if accepted, to classroom use as he deems best. Examples of these different types of opportunity follow.

(a) Thousands of science teachers and students have been invited to visit federally operated research installations. For example, the Public Health Service has opened to organized tours its Sanitary Engineering Center in Cincinnati (Ohio) and its National Institutes of Health in Bethesda (Maryland). The National Bureau of Standards in Washington recently opened its laboratories to organized groups interested in various aspects of the physical sciences. The Oak Ridge Student Educational Tour Program has guided thousands through the Atomic Energy Museum and certain unclassified research areas of the Atomic Energy Commission's Oak Ridge facility.

(*b*) During the summer of 1956, a group of 50 National Science Foundation Summer Institute Fellows in the physical and biological

1. Dwight D. Eisenhower, Press Release, Statement by the President, White House, April 3, 1956.

sciences were assigned for half-days for six or seven weeks to the laboratories of the National Institutes of Health, where they participated as junior members of laboratory research teams and were day-to-day participants in the research program.

(*c*) The National Science Foundation has instituted programs of graduate science study for teachers. These include the Academic Year Institutes, presently 32 in number, each of which provides for approximately 50 teachers of science and mathematics and also include more than 300 summer institutes for a like number of teachers in each. In a number of metropolitan communities, in-service institutes are provided for teachers engaged in their regular employment. In addition, fellowships for science and mathematics teachers have been made available by the Foundation to enable teachers to study in such institutions as they may choose.

The Oak Ridge Institute of Nuclear Studies (ORINS), in cooperation with the National Science Foundation, sponsors eight-week summer training courses for teachers in the handling and use of radioisotopes and in radio-biology. These are held on various geographically distributed college and university campuses.

(*d*) For two successive years, the National Cancer Institute has awarded a sizeable grant to the National Science Teachers Association for the purpose of conducting the Science Teacher Achievement Recognition (STAR) program, the purpose of which is to encourage the development of creative ideas, teaching materials and techniques, and special laboratory exercises. The grant was awarded in appreciation of the importance of the science teacher in developing a pool of young scientists from which may be recruited future leaders in research, science teaching, and other science professions. The subject matter of award-winning projects sponsored by the program cuts across the entire school science curriculum. Cash awards and other types of recognition have been given to several hundred teachers. Selected winning entries have been published.[2]

The Physical Science Study Committee was organized in 1956. Its program, discussed in later pages of this chapter, was administered under grants totaling over two million dollars from the National Science Foundation and several private foundations. Several hundred

2. *STAR Ideas in Science Teaching*. Washington 6: National Science Teachers Association, 1957.

scientists, educators, and teachers from various schools, colleges, and other institutions have participated in the PSSC's program of completely revising the syllabus of secondary-school physics and developing new physical-science teaching aids. In 1958, the PSSC program was incorporated into a larger program under a new body, Educational Enterprise, Inc. The PSSC project alone is to run for four or five years.[3]

(*e*) A committee of junior and senior high school teachers of the Cincinnati Public Schools has observed and examined the basic and applied engineering research at the Sanitary Engineering Center of the United States Public Health Service. With the co-operation of members of the technical research staff, a set of twenty experiments was developed by the committee for use in biology, chemistry, and physics in the school laboratories. The experiments were in the fields of water pollution and treatment, radiological health, atmospheric pollution, and milk and food technology.[4]

The National Cancer Institute held a one-day program for science teachers. Small groups were ushered into a series of medical research laboratories, where they observed experiments either under way or specially devised for the occasion. Topics and experiments included enzyme activity, isotopic tracer techniques, tissue culture, genetics, and chromatography.[5] Staff investigators were available for explanation and consultation, and the teachers were furnished sets of complete details of the experiments.

The Oak Ridge Institute of Nuclear Studies (ORINS) has circulated throughout the country multiple units of a traveling atomic energy demonstration exhibit specially designed for the presentation of the fundamentals of atomic energy to high-school students in assembly programs and in classrooms.

ORINS has also developed a Traveling Science Demonstration Lecture Program under the sponsorship of the National Science

3. "The Physical Science Study: Building a New Structure," *Science Teacher*, XXIV (November, 1957). A series of four articles.

4. "From Research to Classroom Laboratory: A Series of Demonstrations on the Science and Engineering of Man's Environment for Healthier Living," *Science Teacher*, XXV (February, 1958), 16–24; (March, 1958), 77–81; (April, 1958), 130–36; (May, 1958), 192–99; (September, 1958), 254–55, 257; (October, 1958), 328–31, 343; (November, 1958), 394–97, 405; (December, 1958), 442–43.

5. "Laboratory Exercises in the Life Sciences," *Science Teacher*, XXIII (March, April, May, 1956). A series of three articles.

Foundation and some industrial companies. Teachers are given three months of special training at Oak Ridge in the fundamentals of atomic energy and then sent out, each with a station wagon loaded with equipment, to visit schools throughout the country during the academic year, where they give laboratory demonstrations and confer with teachers and students.

(*f*) The Naval Research Laboratory in Washington recently inaugurated a series of lecture-demonstrations for science teachers of the metropolitan area, covering such topics as crystals, atomic structure, and heavenly bodies.

In addition to activities and projects such as those described in the preceding paragraphs, many federal agencies engage periodically in special-information projects or employ other devices in the attempt to stimulate the development of scientific and engineering manpower, beginning at the secondary-school level. Some agencies have developed and distributed thousands of brochures describing career opportunities in such fields as mathematics, sanitary engineering, and biology. The President's Committee on Scientists and Engineers recently launched *Local Action*, a monthly newsletter designed to serve as a clearinghouse of ideas for local groups seeking to strengthen science and mathematics education at the community level. The newsletter is devoted to reporting developments in individual communities which may profitably be adapted to conditions prevailing in other areas across the nation.

The U. S. Office of Education is an active fact-finding organization, carrying on a number of surveys designed to discern significant trends and to disclose shortcomings in the country's educational systems.[6] Its specialists in science have provided information concerning the status of science-teaching and a report of needs in the field. Also, the Office of Education has contributed to the improvement of science-teaching through consultation and stimulation provided by its specialists in science.

The Atomic Energy Commission has an expanding information program—furnishing thousands of copies of speeches, scientific documents, charts, and reports to all who request them. The Oak Ridge

6. A representative publication in this field is Kenneth E. Brown and Ellsworth S. Obourn, *Offerings and Enrollments in Science and Mathematics in Public High Schools, 1956*. U.S. Office of Education Pamphlet No. 120. Washington: Government Printing Office, 1957.

Institute of Nuclear Studies has co-sponsored regional meetings devoted to increasing the effectiveness of science fairs as a means of arousing greater student interest in science.

The federal government has at all times recognized the responsibility of the states for public education. At the same time, many federal agencies have realized that a considerable gulf exists between the research scientist or academic scientist and the teacher of high-school science. Cognizant of both the manpower shortage in scientific fields and the need for teachers to keep up with scientific and engineering developments, federal agencies have helped teachers enhance their substantive background in scientific disciplines through financial aid for study (National Science Foundation fellowships, for example) and through observation of or involvement in operations of a scientific nature. In connection with the latter, teachers may examine research and "translate" it for classroom use.

The National Defense Education Act of 1958 includes several provisions designed to strengthen science teaching.[7, 8] Under Title III of the bill, "Financial Assistance for Strengthening Science, Mathematics, and Modern Foreign Language Instruction," state educational agencies may receive federal aid for projects of local educational units which provide facilities and equipment for instruction in the three specified subjects. However, states or local school systems must match federal funds on a one-to-one basis. Nonprofit private schools may secure loans for similar projects. A third provision makes possible federal grants to state educational agencies for expanded supervisory services in the sciences, mathematics, and modern foreign languages as well as for minor remodeling of laboratories. After the first year (1959) these funds, too, must be matched by the states. An appropriation of $300 million has been voted to implement Title III of the bill during the four fiscal years, 1959–62.

The role of the federal government in educational activities will perhaps never be establishd with finality. In a dynamic society, such a situation is not to be expected. The federal government, however,

7. Committee on Labor and Public Welfare, United States Senate, *National Defense Education Act of 1958: A Summary and Analysis of the Act.* Washington: Government Printing Office, September 5, 1958.

8. Ellsworth S. Obourn, "Editor's Column," *Science Teacher,* XXV (October, 1958), 300–301.

has provided support for certain services for states and communities which undoubtedly will improve the quality of science-teaching.

The Contributions of Business-Industry Groups

Business-industry groups have made contributions toward solving the problems and resolving the issues in the teaching of secondary-school science. What is the nature of these efforts? How effective have they been? Why should such groups join in efforts to improve science-teaching? What does the future hold for those sponsors who continue current programs or would launch new ones?

TYPES OF PROGRAMS

Business-industry groups, large and small, have been identified with a wide variety of aids-to-science-education programs. Each deserves recognition by the profession for its gifts of many hours of executive time and of company resources. Among other efforts, industry has provided:

1. Booklets, charts, films, and exhibits prepared expressly for distribution to school groups or as adaptations of sales promotion or training items
2. Exhibits, displays, or mock-ups of the sponsor's products or processes
3. Tours through factories and laboratories with or without interviews with plant operators and research people
4. Contests and awards programs, usually focused on skills and abilities of interest to the sponsor
5. Summer, late-afternoon, or evening courses or institutes held in co-operation with a college or university, designed to strengthen teachers' academic backgrounds
6. Camps or other special summer programs for science-minded high-school students
7. Science-related summer jobs for teachers and advanced students
8. Farmed-out research projects to teachers and students
9. Distribution of equipment and laboratory instruments
10. Business-industry-education days and community resource workshops
11. Speakers for classroom or career-days

12. Inside or outside consultations with production or research people regarding new laboratory exercises, demonstrations, student projects, or other teaching procedures
13. Scholarships encouraging high-school graduates to enter college and teachers to take further course work
14. Subsidization of research or development projects of interest to the science-teaching profession; research-team summer conferences
15. Medals, certificates, or other awards for demonstrated academic proficiency by students or as "science fair" prizes
16. Employment of teachers as part-time technical or educational consultants
17. Provision of TV or radio time to convey messages of interest to the profession and the general public
18. Appreciation banquets and other public recognition events; grants to pay teachers' expenses at professional meetings

EFFECTIVENESS OF SPONSORED PROGRAMS

Sponsored programs, gifts, and awards obviously help to strengthen science education. It is logical to assume, however, that some of these measures are much more effective than others. Among the most valuable contributions to the advancement of science education are the wealth of information recently made available to teachers of science, the introduction of more effective teaching procedures, and visual aids which have been developed by sponsoring groups and shared with the science-teaching profession.

The circumstances under which sponsored programs are launched seem to allow business-industry groups ample opportunity to explore and develop new aids-to-science-education programs. Willingness to look for new and better ways of doing things has led to research and development of new programs—programs that were later adopted and expanded by government, other business-industry groups, or other types of sponsors.

Some programs attempt to strengthen the academic background of teachers either by making it financially possible for them to take additional college or graduate courses in their major subjects or by providing new courses tailored to the needs of today's high-school science teachers.

Nearly all business-industry sponsored programs tend to get under way with almost evangelistic enthusiasm on the part of both the sponsor and the participants. However, if, after a lapse of time, we look for the residues of such programs in the teaching of those who participated in them, in the long-term interests of the students, or in the practices and policies of science education, we find that the influence of some programs has almost completely evaporated while other programs have had a marked and lasting effect. Reasons for this variation very probably lie in the degree to which the sponsored program anticipated and took into account the realities of the classroom situation. In general, programs launched to do something *for* the teaching of science turn out better than those programs designed to do something *to* science teachers or science-teaching.

WHY PROGRAMS ARE SPONSORED

A variety of reasons prompt business-industry groups to become interested in science education. Among them are a sense of obligation, philanthropy, and self-interest.

Some sponsors want to repay institutions for training new employees or for their research and development of processes or products of peculiar interest to the sponsoring group. Some programs reflect their sponsors' community pride and desire to improve community conditions or to perpetuate the American tradition by methods and means not ordinarily financed through taxation.

As for philanthropy, it has always been a part of the American tradition for those who can to show their "love of mankind through deeds of practical beneficence."

Some programs are considered investments which hold promise of returning good will, building prestige, cultivating a potential market, or actually tapping an existing market.

THE FUTURE

Business-industry groups will very likely continue to sponsor efforts to resolve the issues and solve the problems in teaching science in secondary schools. Such efforts should be extended. Potential sponsors will find it increasingly possible to justify the cost of their programs as more and more shareholders come to recognize the benefits of such programs. By studying the case histories of former

programs and broadening the base of their consultation to include teachers or students for whom the new programs are planned, sponsors of programs can avoid investing their resources in something the influence of which rapidly evaporates because it reflects too sharply passing interest or momentarily popular educational policy or practice.

American Professional Societies as a New Force in Science Education

The interest and activity of professional societies in education, especially at the precollege level, may constitute a new force affecting American education. The professional societies of scholars in this country are eager to assist in shaping precollege education. While there has been more activity on the part of the professional scientific societies than of societies in the other disciplines, and much more financial support has been available for science activities, the American Council of Learned Societies and organizations affiliated with the Council, such as the Modern Languages Association and the American Historical Association, are now developing education programs. These programs appear to be significant and timely and promise not only to support the work of the scientific societies but also to provide initiative and direction to scientists.

The phrase, "new forces affecting American education," is suggested by the title of a yearbook published in 1953 by the Association for Supervision and Curriculum Development.[9] In that yearbook there are four chapters in which the forces are discussed under the headings of culture, groups, communications, and research. If the "force" of the professional societies in education had been included in that yearbook, it would have had its place in the second of the four chapters mentioned. The omission of the "force" was not an oversight on the part of the authors of the ASCD yearbook; this force was much less important six years ago than it is today.

There is no doubt that the basis of the present concern of the professional societies is their recognition of the shortage of talent in all American life and a widespread belief that the schools are too

9. *Forces Affecting American Education.* Yearbook of the Association for Supervision and Curriculum Development. Washington: National Education Association, 1953.

little concerned with excellence. Whether or not the schools are in any way to blame for a nation-wide talent shortage, or whether the belief about "excellence" held by the scholars is justified, it should be recognized that the challenges of the future are so great that education must be better at all levels of instruction in the rest of this century than it has been in the first half.

With this assumption as a starting point, the remainder of this section of the chapter will review the activities of the science-teaching societies and the two largest scientific organizations and then present brief accounts of other activities. It is recognized that this procedure may result in the omission of some very important activities. It should be kept in mind that those presented are chosen on account of the familiarity of the author with the work of particular societies rather than on the basis of an attempt to evaluate their merit in relation to others.

SCIENCE-TEACHING SOCIETIES

The National Science Teachers Association (NSTA), like its counterpart in mathematics, *The National Council of Teachers of Mathematics*, has as its primary purpose the improvement of science education at all levels. Although most of its members are secondary-school teachers of science, the membership also includes teachers at the elementary and college levels. Current and future emphasis on science-education needs should result in even greater participation in NSTA on the part of teachers at all levels of instruction. NSTA is the organization which sponsors the programs of most direct benefit to science classroom teachers. Its contributions are made through its journals, meetings, special publications, and special services.

Much assistance is also given to science teachers through other professional science-teaching societies. *The National Association of Biology Teachers* has as a primary concern the improvement of teaching of biology in secondary schools. *The National Association for Research in Science Teaching* is especially interested in the promotion of sound methods of research in science. Through its publications and special reports, teachers can be informed about promising new methods suggested by research. *The American Association of Physics Teachers* is devoted to the improvement of instruction in physics at both the secondary-school and college levels. Its program

has been strengthened by the addition of two full-time staff members to the office of the *American Institute of Physics* (AIP) with which it is associated. *The Central Association of Science and Mathematics Teachers* is a regional organization but serves a valuable purpose in bringing together teachers from two important fields.

In addition to national organizations, there are numerous regional, state, and local science-teaching societies which provide significant services to their memberships.

THE AMERICAN CHEMICAL SOCIETY

Among the major societies with research as a primary objective, the American Chemical Society (ACS), through its Division of Chemical Education, has contributed to the improvement of science-teaching over a longer period and on a more comprehensive basis than any other. The education program of ACS is supported by 151 local sections and the News Service. In working through its local sections, ACS exerts a strong influence on chemistry teachers and students in secondary schools. This aspect of the Society's education program is perhaps its most important one. The Division of Chemical Education sponsors short conferences and longer institutes for teachers, administers standardized tests for the basic undergraduate courses in college, publishes a journal, sponsors annual meetings, and directs a visiting scientist program.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

The Science Teaching Improvement Program (STIP) of the American Association for the Advancement of Science (AAAS), made possible by a grant from the Carnegie Corporation of New York, has two major concerns. These are (*a*) working with scientists in colleges and universities to bring about better acceptance of their responsibility for science-teacher education and for science programs in the secondary schools, and (*b*) the development of constructive working relationships between educators and scientists. A Joint Commission of Science Teacher Education, sponsored by the American Association for the Advancement of Science and the American Association of Colleges for Teacher Education, has been developing a nation-wide study of science-teacher education. The Science Teaching Improvement Program has also worked with a

number of other professional education organizations in an attempt to bring together scientists and educators in work directed toward the improvement of science at all levels. Another major undertaking is the "Study of the Use of Science Counselors" in co-operation with four universities. This study is basically intended to develop sound working relationships among secondary-school personnel, the university science staffs, and the state departments of education. The institutions which have collaborated on the study for the past two years are the universities of Nebraska, Oregon, Texas, and the Pennsylvania State University.

OTHER ACTIVITIES

Other activities sponsored by professional societies may be briefly reviewed as follows:

With the support of the National Science Foundation, major scientific societies in biology, chemistry, mathematics, and physics have sponsored teams of *visiting lecturers*. These persons first lectured only to college teachers, but the program is being extended to the secondary-school level. The lecturers also often address groups of high-school students.

Most of the scientific societies have contributed to the development of *teaching aids* and special materials for students. There is a large body of career materials that has been prepared under the sponsorship of professional societies. Special reference should be made to the teacher-student materials prepared by the National Science Teachers Association, the Botanical Society of America, the National Association of Biology Teachers, and the American Geological Institute. Along with the development of teaching materials, many of the societies have sponsored the preparation of films and have studied other audio-visual aids and their use. The American Institute of Physics has conducted a study of the role of physics in early grades. In addition to the above societies the contributions of the American Chemical Society and the Society of American Bacteriologists might be listed.

Awards to teachers and students have been provided, both locally and nationally, by the Science Teacher Achievement Recognition program, an affiliate of the National Science Teachers Association. Outstanding teachers have also been recognized by the chemists,

physicists, and engineers. The National Society of Professional Engineers also has an award program.

Many science teachers have been assisted by *summer employment* programs sponsored by such groups as NSTA, ACS, and AIP.

THE FUTURE

The Interim Report of the Subcommittee on Research and Development of the Congressional Committee on Atomic Energy has indicated the most important causal factor of the current shortage in science talent:

> It is important to recognize at the outset that these serious shortages are not a sign of failure but an indication of startling success. A way of life has been created in which the demands made for superior skills in every field have become so tremendous that growth and expansion have become constant elements of the normal pattern. A society has been created in which progress is not simply a matter of occasional spurts and short-term crises. Rapid progress has become a normal part of our national life, and the skilled manpower to keep up with this steadily and rapidly advancing march of progress will be in demand for years to come.[10]

In the decade ahead it will be clearer how effective the new force provided by the action of professional societies will become in American education. Teachers at all levels can help make this force effective in the direction of their choice by familiarizing themselves with the literature and programs of the professional scientific societies, working with them, and assisting in the implementation of those of their proposals which appear to be sound. A listing of representative organizations appears in the chapter bibliography.

The Efforts of Private Philanthropic Foundations

In 1953 there were 4,029 private philanthropic foundations in the United States. Their combined assets of $4.5 billion furnished some $371 million annually for allocation to worthy projects in many fields.[11] Education was probably the leading benefactor. Of the 664 foundations reporting in 1954, 72.4 per cent expressed interest in education or made grants to support work in that field.

10. Interim Report of the Subcommittee on Research and Development of the Congressional Committee on Atomic Energy.

11. F. E. Andrews, *Philanthropic Foundations*, pp. 17, 278. New York: Russell Sage Foundation, 1950.

Grants by these foundations to improve various aspects of the secondary-school science program may be divided into three categories:[12] In the first category are the grants to support either imaginative or novel studies, or programs aimed at changing national policies and practices; the second category embraces grants to colleges and universities to support special graduate or training programs for secondary teachers and pupils; and the third group includes grants for local programs or projects. In general, the larger foundations provide grants to projects in categories one and two. The smaller foundations, often with geographically limited interests, tend to support projects in categories two and three. They are rendering very effective service through awarding grants in these areas, and schools with needs which cannot be met out of their budgets frequently receive such aid on request. As an example of the type of assistance that may be given, the Sears Foundation, in 1957, contributed six Geiger counters to the Roswell (New Mexico) schools for use in the science classes.

PROGRAMS AIMED AT NATIONAL POLICIES AND PRACTICES

Programs designed to change national policies and practices usually receive the most generous grants. In 1957–58, for example, the Physical Science Study Committee[13] of the Massachusetts Institute of Technology received $500,000.00 from the Ford Foundation, $250,000.00 from the Alfred P. Sloan Foundation, and $200,000.00 from the Fund for the Advancement of Education (FAE). Also in 1957, the Fund for the Advancement of Education granted $500,000.00 to the University of Florida to place the first complete course in high-school chemistry on 160 half-hour sound films. This fund also gave the University of Wisconsin $104,940.00 to test the effectiveness of the high-school physics course, filmed in Pittsburgh, on students from 50 to 70 communities.

12. *American Foundations News*, Vol. V (1957) and Vol. VI (1958). New York 3: American Foundations Information Service (860 Broadway). Published eight times per year. See also W. S. Rich, *American Foundations and Their Fields*. New York: American Foundations Information Service, 1955 (seventh edition).

13. See pp. 175–76 for further discussion of the Physical Science Study Committee program.

TRAINING PROGRAMS

An example of assistance to training programs is a grant of $100,000.00 to Harvard University by the Alfred P. Sloan Foundation for the period of 1958 to 1960 to establish fellowships for secondary-school science teachers in the Harvard Graduate School of Education. The Sloan Foundation also gave $27,600.00 to the University of Michigan for 1958–59 for financial assistance to secondary-school science teachers working for advanced degrees. In 1958 the Shell Companies Foundation, Inc., announced 25 four-year scholarships for high-school Seniors who plan to teach high-school science or mathematics and offered to increase the number by 25 each year until 1961 when the annual cost of the Foundation's scholarship awards will be approximately $125,000.00. This Foundation has enlarged its summer program at Cornell and Stanford to one hundred teachers, each receiving $500.00 and all expenses.

During 1957–59 the Esso Education Foundation gave $140,000.00 to support in-service institutes at New York University for two hundred high-school biology, chemistry, and physics teachers. Each teacher received a stipend of $250.00 for the academic year of his attendance.

Summer programs have been sponsored by Westinghouse, General Electric, Crown-Zellerbach, and other concerns. The Thomas Alva Edison Foundation sponsors annual nation-wide science-education institutes, conferences on co-operative education, and a state project co-ordinating science education with industry as well as other projects designed to improve science-teaching in the United States.

GEOGRAPHICALLY LIMITED PROGRAMS

With respect to more limited programs, we may group the efforts of such foundations as the Hill Family Foundation which made grants of $24,200.00 to the Minnesota Academy of Sciences to strengthen the teaching of science and mathematics, a grant of $9,000.00 to the University of Minnesota for summer institutes in high-school biology, and $16,500.00 to the public schools of St. Paul, Minnesota, to aid in developing an experimental program for gifted high-school students with interest in and aptitude for science or

mathematics. The Dorr Foundation in co-operation with Loomis Institute supports a precollege science center in Windsor, Connecticut. The Phelps-Stokes Fund of New York conducted institutes at Howard University for three summers primarily for teachers of science and mathematics from Alabama, Georgia, Mississippi, and North Carolina. This Fund will continue to supply traveling science libraries and kits through 1959 and will provide additional funds to support the follow-up activities of these institutes. The Frontiers of Science Foundation of Oklahoma, Inc., is concerned with the general aspects of advanced education in science and mathematics. These include the identification and development of abler youth; attraction of scientific and engineering laboratories to Oklahoma; strengthening of personnel and facilities for research and development in science, mathematics, and education; and the development of better public understanding of modern science and its impact on society. On a $100,000.00 annual budget, it supports state-wide conferences on the improvement of the science curriculum, awards research grants to scientists in Oklahoma's smaller colleges, provides development grants to public schools for projects in television education in science and mathematics, and supports a traveling science lecture series for high schools. The International Paper Company has recently, through its Foundation, financed an educational survey conducted by a major college in six states and, on the basis of that survey, has instituted educational-improvement programs in the southern communities in which its plants are located. The corporation's activities were then expanded on the basis of another survey to include its plant communities in three northern states.

PROGRAMS INCLUDING THE EDUCATION OF SCIENCE TEACHERS AND PUPILS

In addition to financing programs specifically designed to improve education in science, grants have been given for studies or programs which include science. A good example is the $350,000.00 grant by the Carnegie Corporation to the Educational Testing Service for the support of a two-year study on the American high-school. Another is the $986,000.00 grant from the Fund for the Advancement of Education for a nation-wide program in the use of television in the schools. Others are the $80,000.00 Carnegie Corporation grant to the

University of Louisville to provide summer-school scholarships for superior high-school students, and the Lilly Endowment grant of $36,000.00 to MacMurray College to institute a three-year experimental course for advanced high-school students.

Americans gave $272,734,000.00 to private education in 1956–57, and business corporations supplied an additional $150 million to colleges and universities.[14] The private philanthropic foundations granted $319,085,152.00.[15] Accepting these figures, we may conclude that the grants specifically for any aspect of the science program in the secondary school received far less than 1 per cent of the total funds granted for educational purposes by private philanthropic foundations in 1957. The total granted specifically for secondary-school science in 1957 and thus far in 1958 is less than $2 million.

College and University Programs

Prior to World War II the demands for scientific and engineering personnel were moderate, and colleges and universities had no problem in meeting the demand. Currently these institutions are experiencing an unprecedented demand for engineers and physical scientists, a demand they have been unable to supply. As a consequence, science educators have become intensely concerned with:[16] (*a*) improving the quality of science education at all levels, (*b*) seeking means to initiate science study earlier, (*c*) inducing a higher proportion of gifted students to study science, and (*d*) making better use of teaching time.

At present there are many activities carried on by colleges and universities in their attempt to meet this challenge. Much of this work is in co-operation with other agencies and will be discussed in other sections. In treating the activities which are primarily in the domain of the colleges, references are made to specific institutions as examples. The reader is cautioned not to conclude that the colleges

14. *Better Schools,* IV (June, 1958). New York 16: National Citizens Council for Better Schools (9 East 50th St.).

15. There are differences in the estimates of private aid to education in 1957. Alfred Hill estimates that $833 million from private sources was received during that year by 910 colleges. (*New York Times,* p. E9, June 29, 1958.)

16. See, as an example, the report of the National Research Council and American Institute of Physics, "Conference on the Production of Physicists," *Physics Today,* VIII (June, 1955), 6–20.

mentioned are unique nor that the ones selected are the best examples. Activity is intense in many institutions, and many worthy programs are not publicized adequately.

In view of the diversified teaching assignments in our schools, science teachers often need a broad, extensive preparation rather than the narrow departmental major. As a result, many institutions provide programs of considerable latitude. San Jose State College, for example, offers majors in conservation, life science, physical science, and general science. At Iowa State Teachers College students may major in general science, biological science, chemistry, or physics. Noteworthy are the facts that all students must take a course in the history and philosophy of science and that all science teachers must take certain basic work in all science areas. Another feature of the program is that exemption from specific requirements is granted to those demonstrating proficiency on an examination. The University of Wisconsin offers a major in natural science based on fifty-five semester hours, a reasonable minimum, in science.

Similarly, an awareness of the limitations of the prevailing graduate programs has led to innovations in Master's degree requirements. The policy of many school boards to pay teachers on the basis of earned degrees rather than specific preparation has made the Master's degree a desired objective. The Master's degree in a subject field has required work in a narrow area, often dealing with topics which have little direct application in high-school science. In addition, the problem of securing a thesis topic of appropriate difficulty has kept many teachers out of the program. On the other hand, the Master's degree in education usually has not prescribed sufficient credit hours or has even omitted work in the subject-matter fields. One recent development has been the much heralded Master of Arts in Teaching offered by Yale, Johns Hopkins University, and several other institutions. Other institutions, notably Oklahoma State University and the University of Wisconsin, designed programs leading to a Master's degree in connection with the Academic Year Institutes of the National Science Foundation. The University of Colorado awards the Master of Basic Science upon completion of a thirty-hour program of lower-level graduate courses in science and mathematics. This program is based on the concept of breadth rather than depth in a single subject. Iowa State Teachers College offers a flexible pro-

gram to be planned by the student and a graduate school committee. Facing such variety in available programs, the prospective candidate is obliged to study the relative merits of the programs described in the graduate bulletins.

Many colleges have revised their curriculum and degree requirements as well as a considerable number of courses. While no analysis has been made of the changes in content, particularly noteworthy is the frequent claim that courses are designed specifically for teachers and are organized around principles, ideas, and generalizations.

Because courses in the earth and biological sciences, particularly, are too removed from situations which give reality and meaning to verbal information, a number of institutions have experimented with school camping for science instruction. Michigan State University, Washington State College, University of Washington, University of North Carolina, Northern Illinois University, and Southern Oregon College are representative of the leaders who are stressing outdoor activities in connection with education. Not all the experimentation has been at the high-school level. We often find objectives other than science stressed at these camps; but there are possibilities in this program which merit development.

Summer research assistantships have been made available to high-school science teachers by a number of institutions.[17] These assistantships enable the teacher to gain research experience and knowledge to enrich his high-school teaching.

If any one activity were to be selected as the most significant, the Advanced Placement Program[18] which is being adopted widely in our schools would be one of the major contenders. In this program, outstanding pupils are taught in high school the equivalent of the content of a college course. Upon successfully completing an appropriate examination, the pupil is given college credit at the co-operating college of his choice. For the able, ambitious student, this presents an opportunity to take an additional course either in his area of specialization or in one of the supporting areas while working on his baccalaureate degree. Anyone desiring information about the out-

17. "Summer Research Assistantships for Science Teachers," *Science Teacher*, XXV (March, 1958), 86–87.

18. "High School Students Earn Credit toward University Entrance," *Bulletin of the National Association of Secondary School Principals*, XLII (February, 1958), 86–89.

comes of a science course of this type is urged to read Summers' account of the Columbia High School (Maplewood, New Jersey) chemistry course.[19] Programs of this type will be successful in school systems where gifted students are identified early and given enriched and accelerated science and mathematics programs in the elementary grades and junior high school. A word of caution: Programs of this nature must be restricted to talented youngsters taught by highly qualified teachers with equipment and facilities to teach college-caliber courses.

In conclusion, the recognition by college faculties of the importance of secondary-science teaching has resulted in (*a*) changing and strengthening the undergraduate and graduate programs of science teaching, (*b*) revision of courses to meet subject-matter and professional needs of teachers, (*c*) experimentation with camping as a means of making science instruction more realistic, (*d*) summer employment of teachers in positions offering opportunities for learning, and (*e*) development of an advanced placement program to provide acceleration for able and ambitious students. If the interest shown by colleges and universities continues, as it ought, the next decade should prove to be much more productive than past decades.

Concluding Statement

The present and projected efforts of various groups to supplement the work of the local and state school systems in improving instruction in secondary-school science represent a considerable force. Unfortunately, no one has made a real assessment of the effect of the various programs; and, as a matter of fact, it would be extremely difficult to design a study for this purpose. It seems obvious, however, that the programs have had considerable impact on teaching secondary-school science and that the general interest in science has produced some good results. If there has been any major fault, it is, perhaps, a lack of co-ordination of efforts.

Some questions might also be raised about the emphasis and purposes of many of the programs. Present programs tend to mix concern for better science instruction with concern for educational provision for abler youth and a "toughening" of the secondary-school

19. Donald B. Summers, "College-level Chemistry for Gifted High-School Students," *Science Teacher*, XXIV (September, 1957), 220–24.

curriculum. Very infrequently are these programs aimed at the improvement of the general-education effectiveness of precollegiate-science courses, or with educational provision for the less-able segment of the public school population. However, since the programs merely supplement a total science curriculum, this emphasis may not be inappropriate.

In a few instances, groups have failed to involve school personnel at the planning stage for their programs, with a resulting disregard for the purposes of secondary education and the realities of school situations. Happily, there appears to be little desire on the part of the majority of the sponsoring groups to gain control of the secondary-school science curriculum. As in any democratic operation, the interested parties wish a hearing for their points of view, but, at least at the present, they seem willing to utilize their financial and intellectual resources to develop programs which are auxiliary to the school's existing programs. Nor have the efforts of these groups destroyed the initiative of the local and state school authorities. In most instances, it would appear that the reverse is true, so that local and state systems are directing more of their professional effort and financial support to high-school science than ever before. It would seem that, as long as the local school units retain both initiative and control, the secondary-school science program can benefit from the financial and ideational contributions of business-industry groups, professional societies, philanthropic foundations, colleges and universities, and the federal government. The delineation of issues and problems in the preceding chapter may provide direction for the evolving programs of the various agencies.

Representative Professional and Scientific Organizations

PROFESSIONAL

1. American Association of Physics Teachers (*Physics Today* and *American Journal of Physics*), 57 East Fifty-fifth St., New York 22, New York.
2. Association of Geology Teachers (*Journal of Geological Education*), University of Wichita, Wichita, Kansas.
3. Central Association of Science and Mathematics Teachers (*School Science and Mathematics*), P.O. Box 408, Oak Park, Illinois.
4. Division of Chemical Education, American Chemical Society (*Jour-

nal of Chemical Education), 1155 Sixteenth St., N.W., Washington 6, D.C.

5. Federation of Science Teachers Associations of New York City, Board of Education, 110 Livingston St., Brooklyn 1, New York.
6. Metropolitan Detroit Science Teachers Club (*Metropolitan Detroit Science Review*), 3437 Oakman Blvd., Detroit 4, Michigan.
7. National Association for Research in Science Teaching (*Science Education*), University of Tampa, Tampa, Florida. (Membership is by invitation.)
8. National Association of Biology Teachers (*American Biology Teacher*), 110 East Hines St., Midland, Michigan.
9. National Science Teachers Association (*Science Teacher*), 1201 Sixteenth St., N.W., Washington 6, D.C.
10. Section Q (Education), American Association for the Advancement of Science, 1515 Massachusetts Ave., N.W., Washington 5, D.C. (Primarily interested in research.)
11. American Association for the Advancement of Science (*Science*), 1515 Massachusetts Ave., Washington 5, D.C.
12. American Astronomical Society (*Astronomical Journal*), Yale University Observatory, New Haven 11, Connecticut.
13. American Institute of Biological Sciences (*American Institute of Biological Sciences Bulletin*), 2000 "P" St., N.W., Washington, D.C.
14. American Institute of Physics (*Review of Modern Physics* and *Review of Scientific Instruments*), 57 East 55th St., New York 22, New York.
15. American Museum of Natural History (*Natural History*), Central Park West at Seventy-ninth St., New York 24, New York.
16. American Nature Association (*Nature Magazine*), 1214 Sixteenth St., N.W., Washington 6, D.C.
17. American Physical Society (*Bulletin of American Physical Society*), Columbia University, New York 27, N.Y.
18. American Society of Zoologists (*Anatomical Record*) (with American Association of Anatomists), c/o Goucher College, Baltimore 4, Maryland.
19. Botanical Society of America (*American Journal of Botany*), Michigan State University, East Lansing, Michigan.
20. Ecological Society of America (*Ecology* and *Ecological Monographs*), Duke University Press, Duke University, Durham, North Carolina.
21. National Audubon Society (*Audubon Magazine*), 1000 Fifth Ave., New York 28, New York.
22. National Geographic Society (*National Geographic*), Sixteenth and "M" Sts., N.W., Washington 6, D.C.

CHAPTER XI

Organization and Administration for Curriculum Development in Science

ELLSWORTH S. OBOURN
in collaboration with
ANNIE SUE BROWN and GORDON E. VAN HOOFT

Introduction

The rapid advance of science to a position of dominance in the culture of our times has placed new demands on school and college curriculums in science. There is reason to believe that in years to come the influence of science in the lives of people will call for further marked changes in the sequence and offerings of science in the schools of the nation. The current widespread re-examination of the offerings in science at both state and local levels is in response to the forces which will shape science courses for years ahead.

The older concept of "curriculum" has been expanded beyond the dictionary definition of "a course of study," to embrace the total spectrum of content, resources, materials, and methods of teaching through which the purposes of education are achieved. Thus, as the directory to the ultimate goals of science instruction, the curriculum, next to the teacher, becomes a most important factor in determining the nature of science education. This chapter will consider some of the procedures and developments that are essential to curriculum-planning in science for this critical and challenging period.

The Nature of the Curriculum in Science

The nature of the science curriculum is fully discussed in other chapters of the yearbook. In this chapter, therefore, it is necessary to consider only the nature of its structure as a factor in its usefulness.

SHORTCOMINGS IN CURRENT PRACTICE

Function of the Curriculum. The true value of the curriculum may be determined by the extent to which it is effective in promoting the achievement of the purposes of science education. Syllabi, courses of study, and curriculum guides have long been little more than outlines of science content, the implementing details of which were designed for the one purpose of promoting the mastery of the subject matter.

Curriculum personnel should be reminded constantly that the mastery of content is only one of the purposes of a science program. Other purposes, such as the development of critical thinking, attitudes, interests, and appreciations, while somewhat less tangible, may be more intimately related to changes in the behavior patterns of the learner. Perhaps science teaching has fallen short of its fullest potential because curriculum-makers have placed so much emphasis on attaining perfection in the mastery of content and have failed to consider the content as the means to the end of other less tangible outcomes.

THE NEED FOR MORE IMAGINATIVE SCIENCE CURRICULUM-PLANNING

As we look forward to the increasing importance of science in the lives of people and with the hopeful expectation that every person who studies science will acquire attitudes and behavior patterns which reflect better value judgments, deeper insights and appreciations, and more abiding science interests, curriculum-planners should not lose sight of the potentialities of the curriculum structure for attaining these outcomes.

There is need for creative and imaginative thinking on the part of curriculum designers, particularly in connection with their search for new patterns for curriculum documents that will aid the classroom teacher in directing learning more specifically toward the less tangible outcomes of instruction. And it must be emphasized that these outcomes are achieved with young people only as day-to-day learning experiences contribute to their attainment.

Research in science education has provided a sound basis of procedure for the selection of the content of the curriculum. The sci-

ence principles have been determined by the studies of Robertson,[1] Wise,[2] and Martin;[3] effective experiments, demonstrations, and learning experiences which can be used to develop an understanding of the basic principles have been described by Miles[4] for the physical sciences, and by McKibben[5] for the biological sciences; and the desired attitudes and needed problem-solving skills have been depicted in studies by Curtis,[6] Keeslar,[7] Barnard,[8] and Obourn.[9] The basic principles of biological science[10] and physical science[11] and also the attitudes and skills of problem-solving to be acquired have been presented in publications of the U.S. Office of Education in a useful form for curriculum-workers.[12]

1. Martin L. Robertson, "A Basis for the Selection of Course Content in Elementary Science." Doctor's dissertation, University of Michigan, 1934.

2. Harold E. Wise, "A Determination of the Relative Importance of Principles of Physical Science for General Education." Doctor's dissertation, University of Michigan, 1941.

3. W. Edgar Martin, "A Determination of the Principles of the Biological Sciences for General Education." Doctor's dissertation, University of Michigan, 1944.

4. Vaden W. Miles, "A Determination of the Principles and Experiments Desirable for a High School Course of Integrated Physical Science." Doctor's dissertation, University of Michigan, 1947.

5. Margaret Jean McKibben, "An Analysis of Principles and Activities of Importance for General Education in High School Courses in General Biology." Doctor's dissertation, University of Pittsburgh, 1952.

6. Francis D. Curtis, "Some Values Derived from Extensive Reading in General Science." Doctor's dissertation, Teachers College, Columbia University, 1924.

7. Oreon Keeslar, "The Elements of Scientific Method," *Science Education,* XXIX (December, 1945), 273–78.

8. J. Darrell Barnard, "The Lecture-Demonstration versus the Problem-solving Method of Teaching a College Science Course," *Science Education,* XXVI (October–November, 1942), 121–32.

9. Ellsworth S. Obourn, "Assumptions in Ninth-Grade General Science." Doctor's dissertation, New York University, 1950.

10. *The Major Principles of the Biological Sciences of Importance for General Education.* U.S. Office of Education, Circular No. 308, May 1948. Washington: Government Printing Office, 1956 (reprinted).

11. *The Major Principles of Physics, Chemistry, and Geology of Importance for General Education.* U.S. Office of Education, Circular No. 308-IV. Washington: Government Printing Office, 1956 (reprinted).

12. *An Analysis and Check List on the Problem-solving Objective.* U.S. Office of Education, Circular No. 481. Washington: Government Printing Office, 1956.

SOME GUIDELINES

There is increasingly an interest on the part of professional and lay people in the improvement of science in the schools. This growing interest has been manifest in the large number of conferences of state and national groups which have been held in many parts of the country. The publications which have resulted from a number of these conferences suggest some useful guidelines which may direct curriculum-planning for science into more imaginative channels.[13]

It is proposed that the science curriculum be planned and administered:

1. To give pupils continuous and sequential experiences from the earliest years of the elementary school through the secondary school and on into college.
2. To provide more emphasis on the basic science concepts and principles with somewhat less emphasis on the technological applications of science.
3. To insure methods of instruction that will provide learners with repetitive experiences in such skills of critical thinking as defining problems; hypothesizing; recognizing assumptions; procuring, testing, and evaluating evidence; generalizing; and applying generalizations and principles.
4. To give somewhat less emphasis to the ground-to-be-covered, content-to-be-mastered point of view and increasing emphasis to a concern for how the content may become a means to the attainment of the less tangible purposes of science-teaching.
5. To provide for all who study science, deeper insights into its philosophy, history, and methods of inquiry.
6. To provide for differences in ability and interests of pupils.
7. To make optimum use of all of the human resources that are locally available, such as selected lay groups and professional scientists.
8. To provide continuous and critical re-evaluation.

Organization for Curriculum Development

AT THE STATE LEVEL

Curriculum Problems. Traditionally the responsibility for curriculum development has rested upon state and local school systems.

13. See *The Place of Science and Mathematics in the Comprehensive Secondary-School Program* (Department of Secondary-School Principals. Washington: National Education Association, 1957); "Guidelines for Science and Mathematics" (U.S. Office of Education, Washington, D.C., 1958); and *Improving Science Programs in Illinois Schools* (Edited by William O. Stanley, Harry S. Broudy, and R. Will Burnett. Urbana: Office of Field Services, University of Illinois, 1958).

While the state has a nominal responsibility for curriculum development, the practical responsibility has usually devolved upon local school systems. In these local situations, there has been considerable freedom both for planning and developing science courses. This freedom is evident in the wide variety of curriculum guides produced by local school systems in practically all subjects.

There appears to be a general need for states to assume much more leadership in the matter of defining curriculum patterns in science. Many school and lay people at the local level are seeking curriculum pronouncements and guidelines from the state that permit a reasonable latitude and flexibility for the local school system.

Growing recognition of the need for making better provisions for talented students in science has led some school systems to plan different curriculum patterns for students of varying abilities and interests and for those having different goals. This may result in a trend toward the assumption on the part of the state of responsibility and leadership for defining curriculum patterns which may be modified to meet the needs of local systems.

Personnel To Be Involved. The formulation of a science curriculum suitable for these times is a comprehensive task requiring the services of many groups. While educators should assume the major responsibility, scientists, engineers, and qualified lay personnel must also be involved if the needs of society are to be fully met. Several states and some cities have formed advisory committees on science education which are rendering valuable assistance in advising on curriculum changes.

Most states have general curriculum consultants who have responsibility for curriculum-planning and development. These specialists are in a position to provide leadership but may not have the specialized competence essential for the detailed planning of a program in science.

Many state departments of education are now adding science consultants to their staffs. Such consultants have proved to be invaluable to the state advisory committees and to the general curriculum specialists in organizing and carrying out specific activities related to the development of state programs in science. Their special competence enables them not only to help formulate the broader statewide plans but also to work with local groups so that a pattern may

be produced at local levels which is more consistent with the state program.

It is sound practice, when providing a state curriculum pattern in science, to enlist the assistance and support of a state curriculum committee made up of administrators, science consultants, and science teachers from every level. This committee should have the widest geographic and school-type representation and should work closely with state and local advisory committees as well as with local curriculum-construction committees.

Effective Procedures. The curriculum in science must be based upon acceptable principles of science education and the science needs of all young people for whom the program is planned. Within a given state there will be varying spectrums of youth needs to be met. Some of these needs will be so broad and general that they will apply to every pupil. Others will be so specific as to apply only to special groups. Thus, the science-curriculum pattern must provide for both the general and the more specialized needs of young people.

The broad demands placed upon the curriculum at the state level must involve persons of diversified competencies in the work of both the advisory and the producing committees. Professional people from science and other areas, personnel of science-based industry, educators from colleges, secondary schools, and elementary schools, and laymen generally, all have contributions to make in identifying the general and specialized needs to be met by the science program.

From an analysis of general and specialized needs in science, the broad purposes of science education in a state may be established. It is these purposes which will provide the frame of reference and the guidelines for a science program at the state level. From these, more specific goals may be established in detailed curriculum guides at local levels.

Types of Curriculum Documents. If guidance and help in formulating curriculum patterns are to be provided by the state, good curriculum documents must be available for use by the local committees. The extent and nature of the curriculum documents provided by states vary from a general course of study, in which are listed only the topics to be covered in science, to elaborate teaching guides.

It is important that the state list the needs and present a general

point of view as a frame of reference that will provide the best possible guidance to local curriculum groups. One state appointed a representative committee which produced, for use by local school systems, a document which suggested the need for rethinking and replanning science courses, a basic philosophy of science education, the objectives, the characteristics of an adequate science program, and a specified organization of a good science program for the elementary school and one for the secondary school.[14]

AT THE COUNTY AND LOCAL LEVEL

Curriculum Problems. While there is considerable variation in practice among the states, curriculum development is largely a function of the county and local educational authorities. This task places a heavy responsibility on personnel at these levels for both leadership and planning. If the science curriculum is to meet the needs of pupils, it must be planned as a flexible and developing program. As science changes, its impact on people changes, and so the curriculum must be subject to continuing re-evaluation and modification. It must never be thought of as static and fixed.

The local curriculum pattern should be developed within the framework of the state pattern and yet must reflect curriculum determinants which are unique to a given area. It is quite conceivable that the local programs in almost any science will vary among communities on the basis of their rural, suburban, or urban character.

Another persistent problem at the local level is the degree of specificity and detail to be attained. Some teachers are of the opinion that the curriculum document should be a guide and sourcebook and thus be suggestive of content, method, time to be spent, materials, and pupil activities. There are others who hold that the curriculum document should consist only of broad guidelines which permit the individual teacher considerable latitude in developing the details.

Responsibility of Local Administrative Unit. The superintendent of schools at either the county or local level together with other available representatives of the administrative and supervisory staffs, such as a curriculum director, a science consultant, and the school principals, make up the nucleus from which leadership and direction

14. *Planning for Effective Learning: Science.* Baltimore: Maryland State Department of Education, 1956.

for development of the science curriculum must come. It is the responsibility of these leaders or their representatives to view the science curriculum broadly and in its relationship to the total educational plan of the school system. Lacking the leadership, understanding, and authority on the part of the administrative and supervisory group, curriculum development is quite impossible.

Personnel To Be Involved. In a well-organized science curriculum program the superintendent will assume the responsibility for discussing the program with the board of education, initiating the activity, delegating authority to proper personnel, forming committees, and soliciting advisory and consultant help. In addition, he will provide a sympathetic climate for the undertaking, keep himself informed of progress, deal with new problems, and provide liaison between groups in the community and the board of education.

The curriculum director will be responsible for the over-all planning and development of the program. He will interpret the state curriculum guides, work with general and special committees, request outside consultant help, and serve to co-ordinate all segments of the program. He will also be responsible for suggesting resources and for integrating the science curriculum with the total educational program.

The science consultant will carry the major responsibility for selecting and working with the production committees and for providing guidance and direction in those instances in which the program calls for specialized knowledge of science and science teaching. He will represent the production groups in the over-all planning committee and will further serve to make optimum use of outside consultants and other resource personnel.

The school principal will provide, as best he can, a good climate for the curriculum-development program in his school, encourage teachers to serve on production groups, provide time for teachers to work on the program, and keep informed regarding progress as it affects the school. The working committees will be selected from the science-teaching personnel including the heads of science departments, helping teachers, and classroom teachers. It is with this group that the major responsibity for curriculum production will lie. Its members have the greatest competency with respect to subject-mat-

ter preparation and also have the clearest understanding of pupil and classroom problems.

The composition of these working groups will be broadly representative, both in the elementary and secondary school. It is desirable to have representation from every level of instruction in the elementary school; even in curriculum work in a specialized science such as biology, it is wise to have teachers of other sciences involved.

Members of the working committees will be responsible for understanding the over-all curriculum pattern, for developing the detailed curriculum outlines, for testing the materials in their classes, and for producing the revised and final documents.

Effective Procedures at the Local Level. The format of the pattern for curriculum development in science will vary from one locality to another. Some procedures which have been tried and found useful are reviewed in the following paragraphs.

Several school systems in various parts of the country have found a local curriculum advisory committee useful. This committee usually includes lay and professional personnel much on the same pattern as state advisory committees. These committees have proved to be effective in advising on policies and in securing the support of local parent, professional, industrial, and labor groups. They have also served in providing resources for curriculum development and in obtaining advice from local scientists and other personnel.

The local planning committee is an essential part of any curriculum undertaking. It is usually composed of a broad representation of administrative, supervisory, and teaching personnel. This committee formulates policies, provides over-all co-ordination for the program, suggests working committees, and serves in other capacities to promote curriculum development.

The local working committees are selected from the science-teaching personnel. The nature and scope of the program determine the number and the functions of the various committees. For example, if the program involves a complete revision from kindergarten through secondary school, there might be committees representing the primary, intermediate, and junior high school levels as well as committees for such specialized science areas as biology, chemistry, physics, and advanced general science. Other committee formats might be organized. Regardless of the committee pattern adopted, there

should be frequent opportunity for committees to exchange ideas and to learn of progress made in other groups.

After the first working documents have been produced by these committees, it may be necessary to conduct in-service workshops for those classroom teachers who will be involved in the initial tryout of the program. The tryouts should be undertaken in representative situations, and evaluations should be as objective and as constructively critical as possible. "Tryout" teachers should keep careful records of their experiences with the new program, and pupil reactions should be obtained when possible. These reactions to the experimental materials should be examined and discussed, and the most valid should be reflected in the revision.

Some local school systems have found it desirable to conduct several tryouts before producing a final curriculum document. In fact, there is much to be said for a continuing evaluation and revision of the science curriculum as a means of preventing it from becoming static in a period in which science is changing so rapidly.

Efforts of State and Local School Systems

Significant attempts have been made by many state and local school systems to improve the quality of the secondary-school science program. Such efforts have been reflected by the publication of new courses of study, provision for increased consultative and supervisory services, an increase in the number of workshops and conferences, support of summer and academic-year institutes, and other in-service opportunities for teachers, and, most importantly, by the resulting modifications of programs designed to solve some of the problems of curriculum revision.

An example of a significant effort at the state level to revise existing courses of study may be found in New York State in which a continuous science-curriculum revision program has been under way since the first of a series of state-wide committees was appointed in 1947. These committees of high-school and college teachers, working under the direction of an over-all science advisory committee, have completed a major revision of the courses of study in general science, biology, earth science, chemistry, and physics.[15] In the ex-

15. *Biology: An Outline of the Scope of Content and Related Understandings of a Course in the Science of Living Things* (1958); *Chemistry and Physics: An Outline of the Scope of Content and Related Understandings of the Course of*

perimental phase of each revision, preliminary editions of each course of study were used for two or three years in representative schools throughout the state, involving many classroom teachers in further refinement of the materials. These new courses of study are now in use in all schools in the state. The State Regents' examination has been an important factor in speeding the implementation of these courses of study. As with the courses of study, these examinations are also prepared by committees of teachers and are designed to evaluate the core of required material in the course of study. To assist teachers a series of handbooks has been developed that contain many suggestions for pupil activities, demonstrations, and projects as well as other teaching material and aids. Another series of resource units, designed to assist local schools in developing programs for pupils of low ability and little interest in science, is partially completed. Units developed for a course in physical science utilize an approach that is less theoretical and less quantitative than that used in the regular courses. All of the handbooks and resource units have been developed by classroom teachers and represent collections of experiences and practices that have proved successful in the classroom.

Similar procedures have been used in many other states in the production of preliminary courses of study, guides for teachers, and other resource material. In Georgia, for example, the work of a series of state-sponsored workshops and conferences has resulted in an exemplary guide.[16] The State Department of Education appointed a committee of the Georgia Teacher Education Council to make a preliminary study of the adequacy of science instruction in the public schools. After a careful examination of the situation, this committee made a series of specific recommendations. Following this, a state curriculum committee was appointed to study student needs in

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Study (1957); *Earth Science: An Outline of the Scope of Content and Related Understanding* (1955); *Exploring Space: A Resource Unit for a Course in Physical Science* (1957); *The General Science Handbook*, Parts 1, 2, and 3, (1951, 1952, 1956); *Physics Handbook* (1956); *Science 7-8-9: Suggestions for Developing Courses of Study in General Science* (1956); *Using Chemicals: A Resource Unit for a Course in Physical Science* (1956); *Using Electricity: A Resource Unit for a Course in Physical Science* (1953). Albany, New York: Bureau of Secondary Curriculum Development, New York State Education Department.

16. *Science for Georgia Schools*. Atlanta: Georgia State Department of Education, 1957.

light of the recommendations. Following orientation meetings, this committee became a steering committee with responsibility for:

1. Arranging for college, high-school, and elementary-school personnel to meet for consideration of objectives of science education in the public schools of Georgia.
2. Setting up science-curriculum work conferences which were financed by the State Department of Education.
3. Selecting teacher participants from the elementary, secondary, and college levels for the curriculum conferences.
4. Directing the participants in the preparation of a sequential science program, Grades I–XII, and a tentative resource guide to implement the program.

During the summer of 1957 working committees were employed to work on the development of a guide at Atlanta University and Emory University. Emphasis was placed on the objectives enumerated in the National Society's Forty-sixth Yearbook (*Science Education in American Schools*), and special attention was given to functional concepts and the understanding of principles. The tentative publication, "Science for Georgia Schools," was prepared in two parts: Part 1, "Philosophy and Objectives of Science Education"; and, Part 2, "Suggestions for Teaching Science." Somewhat similar procedures culminated in the recent publication, *A Guide to Teaching Science*,[17] by the Florida State Department of Education.

Typical of the in-service conferences for the improvement of science instruction were those held in Kentucky in the spring of 1957. Five regional conferences were held at the four state colleges and at the University of Kentucky. Through more effective statewide communication and co-operation, Kentucky is attempting to strengthen its science programs at all levels. Numerous other conferences and workshops have been conducted in other states. One typical conference that involved nationally-known scientists and science educators was conducted by the Great Neck Public Schools, Great Neck, New York, in the spring of 1958.

Direct support to in-service programs was provided in legislation passed in New York State in the spring of 1958. Nearly a half-million dollars was provided to support summer and academic-year institutes and in-service programs for science and mathematics teachers

17. *A Guide to Teaching Science*. Tallahassee: Florida State Department of Education, 1957.

during 1958–59. In addition, another $200,000.00 was provided to encourage experimental programs in New York schools aimed at improving the quality of the science and mathematics programs. These and other state-supported programs supplement those provided by the National Science Foundation and by many private organizations. In fact, many of the poorer trained science teachers who seldom qualify for foundation-sponsored programs benefit from such opportunities.

In many local situations, sequential planning for a science program at all levels and the involvement of classroom teachers in the process of curriculum development have resulted in significant changes in methods of teaching. Any listing of science curriculum materials reveals many publications that have been developed by local school systems. Large cities such as Chicago, Cleveland, Cincinnati, Detroit, New York, Boston, Philadelphia, Rochester, and Atlanta have all developed guides or courses of study for schools in their systems. Smaller systems such as Arlington (Virginia), Brookline (Massachusetts), and Baltimore County (Maryland) have prepared materials for science teachers. In all of these efforts, local teachers working together with the help of consultants from area colleges and universities have conducted programs of action research in their classrooms in connection with the curriculum project.

Individual school systems have also tackled the problem of handling the slow learner and the gifted. Courses in applied sciences are offered in New York City high schools for pupils of low academic ability. Houston (Texas) has developed materials designed to help teachers with the instruction of the abler students in science.[18] Teachers in many school systems are teaching college-level courses in the twelfth grade as a part of the Advanced Placement Program conducted by the College Entrance Examination Board. In such schools considerable experimentation is going on to discover desirable adaptations of the program in grades as low as the seventh and eighth grade for students who will take part in the college-level program in senior high school. The increase in enrolment in modified science courses for pupils at both ends of the ability spectrum indicates that at least some local schools are attempting to provide appropriate science instruction for all pupils.

18. *Providing for the Abler Student in Science.* Houston, Texas: Houston Independent School District, 1957.

State and local school systems have accelerated their efforts to improve the science programs in their schools, particularly since the National Defense Education Act of 1958 made federal funds available. Only as the efforts have involved classroom teachers in the process have they produced desirable results. Much still remains to be done to develop a science program suitable for the needs of students who will face the problems of tomorrow's world.

Emerging Influences in Science Curriculum Development

Traditionally the development of the science curriculum has been the task of educationists. The current concern for improving science teaching has led to the emergence of new forces which are bringing other groups with somewhat different backgrounds of experience and with different approaches into the work of building the science curriculum.

FEDERAL AGENCIES

The National Science Foundation has for several years been providing money for both summer and academic-year institutes for science teachers. While these are primarily concerned with improving the subject-matter backgrounds of science teachers, there can be little doubt that they provide an indirect and healthful influence on the curriculum in science since the participants in these workshops often become members of state and local curriculum committees.

The National Science Foundation has also provided a considerable amount of money to the Physical Science Study Committee[19] which has been engaged in rewriting the course in high-school physics. This effort represents a unique pattern of curriculum revision in science in which physicists have worked co-operatively with science teachers to revise the high-school physics course and to produce new textbooks, laboratory manuals, teaching guides, audio-visual aids, simplified equipment, and library resource materials.

The National Science Foundation has further aided this new curriculum enterprise by devoting regional summer institutes to the training of physics teachers to teach the new course in phyics. Other programs supported by the National Science Foundation are now going forward in biology and chemistry.

19. *Physics: First Annual Report of the Physical Science Study Committee.* Cambridge: Massachusetts Institute of Technology, 1958.

Other federal agencies which have had an impact on the science curriculum are the U.S. Office of Education, the U.S. Department of Agriculture, the Soil Conservation Commission, the Forestry Service, the Bureau of Standards, the Biological Survey, and the Atomic Energy Commission.

EDUCATIONAL TESTING SERVICES

There are several agencies over the country engaged in preparing testing instruments in science and other subjects. These agencies by the very nature of the tests they prepare become a potent force in determining the curriculum.

In general, these educational testing agencies prepare tests to evaluate the content objective as well as power tests which tend to measure some of the more subtle outcomes, such as the abilities of critical thinking and desirable attitudes.

An influence for flexibility rather than rigidity in the curriculum in science can be wielded by these testing agencies if they place greater emphasis on power tests than on tests of specific content. It has been contended that these agencies have operated to make the science curriculum too rigid and that definite steps need to be taken to correct this situation.

SCIENTIFIC ORGANIZATIONS

Many scientific organizations such as the American Association for the Advancement of Science, the National Research Council–National Academy of Sciences, the American Institute of Biological Sciences, the American Chemical Society, and the American Institute of Physics have programs and publications which influence the entire science curriculum or specialized segments of it. In many localities members of these organizations are serving on school boards or on advisory committees for school science programs.

INDUSTRIAL ORGANIZATIONS

The impact that American industry is making on the science curriculum may be illustrated by one of the many examples that present themselves. The Manufacturing Chemists Association is engaged in

a co-operative project with high-school chemistry teachers to provide improved laboratory work in chemistry. It is planned to produce as many as seventy experiments in chemistry which provide students with opportunities to practice the skills of problem-solving and to incorporate the experiment into the ongoing activities of the classroom.

Continuing Evaluation of the Science Curriculum

Science through its method of inquiry is a dynamic and evolving influence in contemporary culture. As the culture develops and changes, new problems and new needs which impinge on the everyday lives of people arise. Thus, individuals are constantly confronted by new problems and new foci of concern as they are compelled to conform to or align themselves with these new environmental forces.

The science curriculum in the schools offers one of the most practicable means for preparing people to cope with life problems which have their antecedents in science and technology. But designers of the science curriculum cannot predict future needs. At best they can only follow a few guidelines which may imperfectly indicate future trends.

Thus, all that can be expected at any time is a science curriculum that is best possible for that period. It can be best only if it has utilized the tested science principles, as one thread in its fabric, and has provided opportunities for pupils to engage in intelligent methods of inquiry, as another. Such a curriculum may help citizens identify and solve new problems as they arise.

Thus, to be most effective for the rapidly changing times in which we live, a science curriculum must be regarded somewhat as the scientist regards a scientific theory from which problems emerge and hypotheses for testing are drawn. The curriculum suffices for the present to guide the science teacher's endeavors, but it is a strictly tentative guide. It is viewed with the understanding that it does not represent something that is absolute and ultimate but that it will be reshaped and enlarged to encompass new developments and discoveries.

If this view is taken, the science curriculum will be subject to constant tryout and evaluation. The program will be a dynamic and de-

veloping one, always subject to critical scrutiny and revision. It will never be permitted to become fixed and static, for when this happens its effectiveness for educating children and youth is largely lost.

The science curriculum, thus conceived, calls for a continuing committee rather than for science-curriculum committees appointed at ten-year intervals. This concept also requires the issuance of revised science-curriculum documents at intervals consistent with the changes and developments which emerge.

CHAPTER XII

The Supervision of the Science Program

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The Nature and Importance of Supervision

Operational problems of one kind or another will quite certainly confront any established organization. If an organizational group is to remain dynamic, it must struggle toward equilibrium in structure at the very time that it is seeking ways to unbalance the equilibrium in order to improve the structure. This conflict between stability and change is blended most successfully in organizations where the expectancy is one of "structural mobility" or "organized change." In such situations the energy typically spent in resisting change is channelled into seeking and fostering types of change designed for the improvement of the whole organization.

THE NEED FOR SUPERVISION

Supervisors are needed to help an organization live successfully as a "family" within its structural plan while at the same time helping to rebuild the structure. Doing this is difficult enough, but doing it with methods which permit acceptance of the supervisor as a member of the "family" is the acid test of modern supervision.

For this difficult role effective supervisors are in constant demand, for the part they play in an organization is somewhat like the role of the catalyst in an organism. Membership in smaller educational organizations is often limited to planners (administrators) and teachers. Such an organization may be very successful; or it may result in the development of an arbitrary plan of action with little provision for reorganization and growth. More flexibility often results if

the administrator provides some time for supervisory work or arranges to have a teacher released on a part-time basis for this type of service.

As a school system grows in size, both advantages and disadvantages emerge. One advantage arises from the fact that, between the administrative and the implemental levels, specialists in subject matter and methodology can be provided to play the catalytic role.

THE SUPERVISOR AS A CONSULTANT

When a supervisory program becomes more inhibiting than catalytic, the reasons are usually less obvious than those indicated in the preceding paragraphs. The latter may be only contributing influences. In an honest attempt to reduce friction and increase the effectiveness of a program, especially in larger systems, a stifling accumulation of rules, procedures, clearances, and general protocol may accrue. Out of this complexity may arise an atmosphere known in popular jargon as "bureaucratic." In this type of organization, the supervisor tends to become so preoccupied with procedure that proceedings grind to a snail's pace. It becomes so difficult or irritating to bring about change that initiative and creativity are stifled.

A new concept is arising in the field of supervision. In some systems the title of supervisor has actually been replaced by the title of consultant. Even where the title has been retained, the supervisor has become a consultant. The word itself denotes the change. A consultant is a person who is sought for suggestions and assistance in planning. The emphasis upon being sought is an invitation to initiative in others. It also means that to be successful a consultant must have something to offer in the way of knowledge and method.

SUPERVISION: A CO-OPERATIVE ENDEAVOR

The modern concept of supervision is one of helping people help themselves. This is also the modern concept of classroom instruction. The supervisor is wise, therefore, to make all details of his approach consistent with the approach he advocates for teachers. If he believes teachers should set a wholesome emotional tone in the classroom, then he should seek a similar tone in the educational system. If he believes teachers should develop experimental-mindedness, curiosity, leadership, and self-analysis, he should seek to bring out

these qualities in the adults with whom he works. If he believes that the teacher should use multiple approaches, employ diverse materials, encourage problem-exploration, and emphasize individual differences, this belief should be reflected in his own activities.

All of this calls for that healthy give-and-take called co-operative planning. The supervisor by no means abdicates the role of leadership, nor does the classroom teacher who organizes the classroom in such a manner that she is freed to be a consultant. People seek the consultant in order to become oriented and to discuss new pursuits. The consultant, in approaching problems co-operatively, helps draw a larger circle with new problems. This may be an extension of a new interest or an enlargement of an old one, but it leads to a desire for leadership in opening up new frontiers.

Teachers may use the consultant approach with students, and consultants may use a similar approach with adult personnel within the educational system—and still the education of youth could be jeopardized if the community does not understand the modern approach. The supervisor uses the same approach with the community which he uses with the adult personnel in the school system and which he encourages teachers to use in the classroom. The attitude is not one of salesmanship of a finished program but co-operative problem-exploration in improving the program.

The State Consultant for Science

A typical state school system might have one thousand secondary schools in operation in one hundred fifty local school units. Each of these schools is an integral part of a complex machine devoted to the job of educating youth. If one were to evaluate the science programs in these schools, a normal distribution would probably be the result. The schools would vary in the effectiveness of their programs from very poor to very good, in much the same manner that members of a heterogeneous biology class would vary in their achievements. However, there would be many schools which failed to realize their potential and operated below their capacity, thus providing sufficient reason for initiating plans for improvement.

THE NEED FOR THE CONSULTANT

The state consultant for science occupies a unique and challenging position in programs for improvement. He works with all schools

and with groups within the schools including administrators, teachers, pupils, and school boards. He endeavors to direct their energies into appropriate channels and to help them formulate plans of action for long-range improvement. He performs a motivating function, an analysis function, and a synthesizing function. The schools with weaker programs are encouraged to analyze their resources with the view of preparing a program which will raise the instruction to a higher level. Schools with strong science programs are guided into well-planned experiments to discover more effective ways of handling the various aspects of the curriculum, and these are translated into procedures which can be used later by all schools.

THE ROLE OF THE CONSULTANT

The science consultant representing a state department of education will find himself involved in the thinking and other activities of many groups. He must work with all groups which are genuinely interested in providing the best scientific education for youth. With these groups his role will be that of a listener, an originator of ideas, a co-ordinator of activities, a procurer of help, and an encourager. In short, he will serve as the director of a team composed of many members, each of whom must be placed in the type of work which will assure the best results.

All of this means that the state consultant in science must know and understand the spectrum of science education in his state which will include bases of the curriculum; relation of administration, teachers, and students to the program; physical facilities; experimentation; and new curriculum materials. When he finds there are gaps in this spectrum, he must work in such a manner that these voids are gradually filled. Unfortunately, this is an unending task for, as one gap is filled, another appears. Therefore, review of the spectrum and efforts to keep it unbroken must be continuous.

RESPONSIBILITIES OF THE CONSULTANT

As indicated in the preceding paragraph, the consultant, to be effective, must contribute to the achievement of the general goals by assisting in the solution of a variety of problems as they arise or become acute. A number of serious gaps have appeared in the science-education spectrum in recent years. One of these is the inadequacy

of teaching personnel with respect to both numbers and training. This problem has arisen because of the upsurge in school enrolments, low salaries, poor working conditions, and the rapid change from an agricultural to a technological society. To make this situation more serious, the subject matter in the various science courses has necessarily undergone rapid change. Perhaps an answer is needed to the question, "What kind of program should be established to provide science teachers who will be able to channel the energies of youth into more productive efforts?"

The solution to this problem must be a co-operative affair, involving the science consultant, the state department of education, the colleges, the science teachers, administrators, and resource persons such as industrial chemists and conservationists. With the consultant as a co-ordinator, these groups can participate in science-teacher work conferences in local school systems and in programs on sectional and state levels. The work of these conferences might be centered on such topics as the cell, the atom, photosynthesis, metabolism, chromatographic analysis, materials and professional organizations. However, such conferences affect directly only those persons already teaching. Paralleling these activities must be others which deal with preservice teacher education. With vitalized programs at the preservice level, progress should be noticeable within a few years.

A second gap in the spectrum has occurred in the area of curriculum. The large volume of scientific information collected cannot be covered in the courses, and, as a result, important questions have been asked: What should be eliminated? What should be added? What sequence should be followed? What should be provided for the rapid learner? What background in science is needed by all citizens? These are only a few of many questions, most of which are difficult to resolve. Again, the science consultant is in a position to provide leadership in the development of good curriculum bulletins and in the planning of workshops and work conferences to attack these problems. But placing a bulletin in the hands of administrators and teachers will not insure beneficial changes. To accomplish needed changes, the science consultant must organize groups of teachers and selected consultants to develop the bulletin and then hold work conferences to study the finished product.

A third gap has occurred in the spectrum in regard to physical facilities for teaching science. The filling of this gap involves more than the provision of funds. A prerequisite is a clear understanding of the activities in which modern-day science students should engage and the type of facilities and equipment which will encourage the many aspects of problem-solving. In helping to fill this gap, the role of the consultant is obvious. He must present ideas to school personnel and architects and lend assistance in designing programs and facilities which reflect the best of available ideas.

Another responsibility of the science consultant is to provide the public with accurate information regarding the status of the science programs in the state. To do this effectively, he will find it necessary to collect and summarize pertinent data each year, and to make his findings available through the press, the radio, and television.

Supervision at the County Level

Harold Spears is quoted as authority for the statement that, "The improvement of instruction for about half of the nation's school children is largely dependent upon the supervision that comes out of the office of the county superintendent."[1] He also reports that half of the counties do not employ supervisors, the superintendent carrying all supervisory responsibility.[2]

In a survey of the 49 states made for this study,[3] it was revealed that science supervision is, to the extent that it exists, provided by general supervisors or by the county superintendent. In some counties, certain county staff members with some competence in science education are employed. A few state departments reported that excellent work in science education was being done by these specialists. Leaders in a number of state departments reported a need for specialized supervisors at the county level, while others indicated a preference for general supervisors who would concentrate their efforts on teaching methods rather than on subject matter.

1. Harold Spears, *Improving the Supervision of Instruction*, p. 235. New York: Prentice-Hall, Inc., 1953.

2. *Ibid.*, p. 236.

3. In June, 1958, an inquiry concerning the status of science supervision at the county level was mailed to all the state departments of education. There were 45 replies.

SPECIAL PROBLEMS

At the Elementary Level. Replies to the questionnaire from the state departments can be summarized thus: (*a*) Elementary teachers, in the main, lack sufficient training in science and tend to shy away from science. (*b*) The combination of not having specially trained supervisors at the county level and not having classroom teachers trained in science renders unlikely any attempt on the part of the two groups to co-operate in the improvement of science education. (*c*) The lack of training indicated in (*a*) and (*b*) above is responsible, in large measure, for the lack of minimum physical facilities for a minimum program in science.

The consensus indicated that the first step in upgrading science-teaching in schools of the county is to obtain competent supervisors who have an interest in science and who would encourage the schools to employ science teachers who are competent and are interested in teaching science. This appears to be essential if children of high ability in science and mathematics are to be identified early and started on their way to science careers.

At the Junior High School Level. Junior high schools are located, in the main, in larger towns and cities in which the county school superintendent's office exerts little or no supervisory control over instructional matters. However, many state departments recognize the possibilities of a co-ordinated supervisory effort among the junior high schools and the upper elementary grades through the county office. Activities such as arranging science institutes for teachers, evaluating teaching materials, organizing county science fairs, and preparing teaching guides could be sponsored by the county superintendent's office in counties in which there are a number of junior high schools.

At the Senior High School Level. The special problem of the supervision of high-school science arises from a lack of county-wide supervision in a situation in which there is real need for it and in which there is already an established agency, the county superintendent's office, to provide it. Some excellent instruction is being provided on the secondary level. Science teachers have done a large amount of original work, but new ideas and methods developed by them have not been made known to other teachers. Thus, there is a

need for high-school science teachers to share ideas and experiences with one another. The teachers who are best qualified to help high-school science teachers are the science teachers themselves, and a natural catalyst in solving this major problem of communication is the county superintendent's office. A few county offices do sponsor newsletters, institutes, workshops, science fairs, exchange visits, and the like. An advantage of these types of activity is that they involve, in most cases, several districts, thus providing wider communication.

THE ROLE OF THE COUNTY CONSULTANT

Responses to the questionnaire from state departments gave general support to the idea that county consultants should be specialists in (*a*) supervision and curriculum, (*b*) the basic sciences, (*c*) methods of teaching science, and (*d*) human relations. The consultant is a resource person, ready to serve where and when needed. His association with teachers in the county should make them more confident of their ability to teach science. He is a leader in the broadest sense.

The science consultant provides liaison between teachers and administrators. He advises the superintendents and principals and reports to them on the progress and needs of the schools. He attempts to develop a unity of purpose among the schools of the county and co-ordinates the over-all effort from kindergarten through Grade XII. He recognizes weaknesses in the programs of the schools; and, in a democratic way, helps teachers and administrators correct them. He places proper emphasis on science instruction and assists in integrating science into the curriculum.

RESPONSIBILITIES OF THE COUNTY CONSULTANT

All of the science consultant's efforts are pointed toward upgrading science education in the county. He works constantly with teachers and administrators to improve instruction and to expand the opportunities afforded children for the study of science. He develops or assists in the development of a science program from the elementary grades through high school; helps develop programs of in-service training; trains teachers in methods of instruction, giving classroom assistance where needed and wanted. The consultant co-ordinates the county program as a whole and evaluates the curricu-

lum in individual schools annually. He assists teachers and administrators in the reorganization of the curriculum and makes arrangements for institutes and workshops for the improvement of instruction.

Supervision in Large City Systems

The attributes of good supervision are the same regardless of the size of the school system; the problems involved, however, are of a different order of magnitude. The number and nature of opportunities for supervision differ from level to level and even at the same level. Although ideas do not easily flow among a large number of teachers, the existence of a large staff makes possible the addition of consultants, specialists, and supervisors with only a small percentage increase in the school budget.

SPECIAL PROBLEMS

At the Elementary Level. The increase of dependence of our way of life upon scientific achievements has convinced educators that science must become an essential part of the elementary-school curriculum. Elementary science is being increasingly introduced in many parts of the country, and the preparation of the elementary teachers to teach with confidence in that field is one of the primary aims of elementary education today. Since many school principals are not science specialists and many elementary teachers have little or no background in science, the problem of adequate supervision becomes a formidable one. A supervisor at the elementary level is called upon to perform many important functions. Among these, the following are suggestive:

1. He must participate in the formulation of a science program which will explore scientific concepts and provide experiences for children from the kindergarten through Grade XII.
2. He must participate in the preparation of resource publications which describe a variety of appropriate activities for implementing the science program.
3. He must engage in a broad teacher-training program designed to provide background and engage in workshop courses which will enable teachers to secure first-hand experiences with science subject matter, materials, and techniques.
4. He must recommend selections of supplies and equipment and proper procedures for obtaining them.

5. He must participate in the formulation of programs for talented students.
6. He must participate in the formulation of continuous in-service science programs which will supplement the initial background courses and workshops and will insure the professional growth of teachers throughout their teaching lifetime.
7. He must evaluate instruction through such methods as direct classroom visitations and follow-up conferences.

There are some elementary-science supervisors who are performing only part of the foregoing functions. In some cities some of these functions are being performed by science specialists. They are usually highly successful teachers, with good backgrounds in science, who are freed from teaching to operate from a field superintendent's office. The specialists visit elementary-school teachers in accordance with an arranged schedule or upon specific request of principals and teachers. The specialists can usually assist only in the performance of a few of the functions. They work with the teachers individually and in small groups. One consultant to every 120 to 150 elementary teachers is recommended.

The evaluation function, together with one or more of the other functions, is usually performed by the principal or assistant principal of the school. Either operates under a disadvantage when he attempts classroom supervision because his background in science may be too meager. Also, principals and assistant principals are so occupied with administrative duties and the entire program of elementary education that they are often unable to provide the leadership needed for science work at the elementary-school level.

In this period of transition, when in-service science training of the present corps of elementary teachers is paramount, effective elementary supervision should remain the joint responsibility of the science specialist and the principal or assistant principal of the school.

To assure the proper supervision of classroom instruction and the professional growth of the elementary-school teachers, it is recommended by some that at least one person who possesses an adequate science background and supervisory training should be assigned to each elementary school. He would be responsible for the supervision of science instruction in addition to other duties.

Supervisors should not disregard the fact that the elementary and secondary schools are operating upon the *same* child at different

stages of his development. Supervision on one level cannot, therefore, ignore the fields of science as they are explored on other levels if it is to assure the proper ordering of scientific concepts and activities for the maturing child. Thus vertical articulation, so obviously needed in our school systems, should be a prime responsibility of the science supervisor.

At the Junior High School Level. From the standpoint of adequate supervision, the situation in junior high schools is at present a little different from that found in the elementary schools. One significant difference lies in the fact that in some larger systems each subject in the junior high school is taught by a teacher specifically qualified in that subject. In this situation, supervision by a general supervisor becomes more difficult. The science supervisor at the junior high school level must perform the same functions enumerated for the supervisor of elementary science. In addition, and because of the rapid changes taking place in the various science fields, these teachers need to be provided with organized in-service science training to bring them up to date.

Since the science supervisor must be a person with extensive training in science, adequate supervision may be attained by utilizing the services of high-school departmental chairmen who understand the science needs of younger students and are qualified in the biological or the physical sciences. Chairmen, who supervise teachers in junior high schools, should be relieved of some classes. Since they are trained for this position, they can perform *all* of the functions of a supervisor.

Another practice which has many adherents is the training and certification of supervisors or consultants in junior high school science. At this level, certification should require broad training in the major fields of science rather than specialized training in a single field. The specialist in junior high school science should not carry a full teaching assignment. The appointment of a junior high school chairman as supervisor or consultant rather than a senior high school chairman would have the advantage which accrues from the former's closer relationship with the junior high school faculty.

It has been amply demonstrated that good supervision will improve the instruction in science, raise the morale and professional status of teachers, and provide the leadership that assures their professional growth.

At the Senior High School Level. Supervision on the high-school level has been provided to some extent in all subject areas for many decades. This supervision has usually been in the hands of chairmen of subject departments. In fact, the success of high-school teaching in large cities has been due chiefly to departmental chairmen who are well qualified in their subject fields.

Science chairmen are also responsible for the science program in their schools. Such responsibilities might include the programming of teachers, classroom visitation, holding individual conferences and department meetings, adapting courses to the needs of students, ordering supplies and equipment, and recommending teachers to be employed.

Supervision in Smaller City and Suburban Systems

The large number of relatively small school systems in the country makes it necessary to study problems of supervision in such systems. Statistics indicate that 75 per cent of American high schools have enrolments of less than three hundred pupils, while 90 per cent have fewer than a thousand.

SPECIAL PROBLEMS

The supervision of the science program in small cities poses a number of difficulties. Its problems include many which are common to those of larger cities as well as those unique to this group. The following are perhaps those of chief concern:

1. In general, the smaller the school population the more limited are the course offerings. Schulz[4] points out that there is no practicable way to separate those pupils who plan careers in science from those for whom science will be only a means to a better life. In each science class there is a great variety of abilities, backgrounds, interests, and ambitions. This fact frequently prevents the formation of advanced classes as well as the efficient operation of special-interest groups. On the other hand, "... small-school educators can look to opportunities that are not hopelessly discouraging. For there are some unique advantages. Large enrollments are companions of large classes. The small-school enrollments in general science and biology average just over twenty while the average for chemistry and physics is somewhat under twenty. The teacher has

4. Richard W. Schulz, "Science Education in Small High Schools," *Bulletin of the National Association of Secondary-School Principals,* XXXVII (January, 1953), 34–38.

an opportunity to know his pupils . . . in a more personal and informal environment. The pupils' homes, interests, community relationships, ambitions, and aptitudes are more than a counselor's record. They are accessible information and make a cogent teaching resource."[5]

2. The smaller the school, the greater the range of subjects assigned to the teacher. Too frequently, the science teacher not only teaches all the science offered but carries additional subjects. In many cases, the teacher is selected for his qualifications in an area other than in science. In contrast, large city systems employ teachers of biology, chemistry, or physics. It behooves the small school system to employ science teachers with a broad science background. This offers some specific administrative advantages.
3. The small system faces serious difficulties in the rapid turnover in science personnel. It is difficult to meet the salary scales of larger systems as well as those of industry and government. This creates a heavy responsibility for the science supervisor whose job it is to recruit, train, and maintain an adequate staff.
4. It is important to keep abreast of knowledge and learning in both science and education. To this end, a good in-service program is mandatory. In smaller cities, the opportunities for in-service training may be limited by the inaccessibility of a university or an extension service. Summer institutes such as those provided by the National Science Foundation are excellent corrective measures for this deficiency. In cities that provide supervisory services it is feasible for the supervisor or consultant to initiate an in-service program. The numerous types of in-service activities provide opportunities for the local staff to secure better understanding and greater skill in solving the problems they meet in their daily work. Departmental meetings in smaller communities may serve this purpose and can create a cohesiveness not easily obtained in large cities.
5. Providing adequate supplies and equipment is basic to a successful program of science instruction. It should be noted that certain fundamental equipment is necessary whether it is used for one class or twelve. This fact creates in the smaller school systems a greater cost per pupil and is frequently a deterrent to a good science program. Many items for use in demonstrations and laboratory work may be constructed by students and teachers from low-cost materials; others may be acquired by purchase or as loans or gifts from community enterprises. There are many source books which are helpful in connection with this problem.[6]

5. *Ibid.*, p. 37.

6. *UNESCO Source Book for Science Teaching* (New York: Doubleday Doran, 1959); *Laboratory and Field Studies in Biology: A Sourcebook for Secondary Schools*, edited by C. A. Lawson and R. E. Paulson. (Washington: National Research Council, National Academy of Science, 1958, preliminary edition).

The choice of items for purchase should be carefully considered and based on the principal needs of the program. Regardless of the size of the city or township, a budget for science-instructional needs, even though small, must be provided. One of the responsibilities of the consultant is to see that appropriate materials are acquired as needed and used to good advantage.

THE ROLE OF THE CONSULTANT

Supervision is an expert professional service which is primarily concerned with the improvement of learning. Thus, supervision deals with the improvement of the total teacher-learning process; orients learning and its improvement within the general aim of education; and co-ordinates, stimulates, and directs the growth of teachers through co-operative leadership. It is deeply concerned with the long-range improvement of science education.

To accomplish these aims and those stated in the first part of this chapter, the supervisor or consultant offers such services as:

1. Developing in-service educational programs
2. Developing a science curriculum
3. Visiting classrooms
4. Establishing and implementing educational goals
5. Planning demonstration lessons
6. Co-ordinating services
7. Suggesting and supplying resource materials
8. Helping in the selection and purchase of textbooks and equipment

The supervisor or consultant also has obligations to raise professional standards, build teacher morale, serve as a resource person, encourage advanced study and research, and interpret the science program to the staff and the community.

One of the major advantages that the science consultant in smaller cities has is the opportunity to know his teachers well and to recognize their strengths and weaknesses. The possibility of developing an exceptional *esprit de corps* is greater than in the larger cities.

PROVIDING FOR ADEQUATE SUPERVISION

In this period of increasing emphasis upon science education, it is imperative that small city and suburban systems provide adequate science supervisory service. It is a prime factor in the improvement of science instruction.

Wherever feasible, a full-time science consultant should be employed to assist with the program in Grades I through XII. In those cities of approximately 200,000, an assistant may be employed who is a specialist in the field of elementary science. In small districts science leadership can be provided by the head of the school science department. This individual should be given adequate time and compensation for performing the services needed to facilitate an ongoing science program.

Within the framework of the American philosophy of education, the schools belong to the people. The schools reflect this concept, and, therefore, will generally be only as good as the citizenry demands.

GENERAL QUALIFICATIONS OF THE SCIENCE CONSULTANT

The science consultant should have a thorough subject-matter background, a basic knowledge in the major branches of science and their interrelationship. In addition to the subject-matter qualifications, the consultant should have professional training in supervision and administration. It is important that the supervisor be familiar with recent developments in the fields of science and education. The consultant certainly must qualify as a superior teacher and should have at least five years of successful teaching experience in the grade levels concerned. It is unrealistic to require previous experience in science supervision since such a small percentage of the school systems, up to the present time, have employed science consultants. A lack of experience in supervision may well be offset by experience within a school system. One of the most important competencies lies in the field of personality. The consultant must be able to work well with his peer group and possess a deep insight into the problems of human relations. He must establish rapport with his teachers in order to carry on free and frank discussions. He must have the ability to assume a leadership role. He should bring to the position a high degree of imagination and creativity. He should be able to recognize the need for specific kinds of help—corrective, preventive, constructive, and creative. He should possess a sense of humor and the maturity to accept decisions adverse to those he has made or would make. These traits and abilities may well serve as guideposts for the selec-

tion of a consultant, and it is hoped that they will develop more fully with experience on the job.

Summary

Certain basic ideas have emerged in this chapter. The writers have pointed out that the trend in supervision is parallel to the trend in teaching. Just as "teaching is not telling," supervision is not inspecting, directing, and rating; it is, rather, motivating, leading, and consulting, a process of co-operative analysis and synthesis involving teachers, administrators, students, and the public.

The need for good supervision is great because the challenges are many. The following problems seem most formidable: hiring better-trained teachers; offering more effective in-service programs; developing more vertical articulation of the science program; promoting more co-operative and long-range planning with the public; making a variety of instructional materials more accessible; giving leadership in the co-operative development of educational experimentation; and providing opportunity and encouragement for science teachers to more nearly approximate in their classrooms the spirit and learning of a genuine research laboratory.

Supervision is valuable in professional growth to the extent its approach to teachers and the public is consistent with the modern approach expected of teachers in the classroom. In general, the best supervisor is the person who is closest to the teacher. While the attributes of good supervision are the same in all systems, the problems of larger and smaller systems take on a different order of magnitude. For instance, the larger the organization, the more the opportunity to add supervisory personnel without greatly increasing the budget. On the other hand, the larger the organization, the more the possibility of overspecialization and overorganization. As America moves toward greater urbanization and the hiring of more supervisory aid, the supervisor in American education should do for teachers only what they cannot do as well for themselves.

CHAPTER XIII

Facilities, Equipment, and Instructional Materials for the Science Program

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As a result of accelerated construction of elementary and secondary schools and the trend toward strengthening science instruction at all levels, many problems which are related to facilities, equipment, and materials for science instruction are becoming of paramount importance. Planning and equipping the new science facilities and remodeling others to provide adequate science instruction will create new problems for school officials, teachers, and parents.

The purpose of this chapter is to present some guidelines which may help in solving some of these problems.

Trends in Science Teaching Which Are Affecting Facilities and Equipment

PHILOSOPHY, PURPOSES, AND METHODS OF TEACHING

A review of science education during the past ten years shows that some important trends are now fairly well established or will become so if recommendations of leaders in science education are fully implemented in the schools of the country. Some of these important trends are:

1. *A movement away* from an emphasis on the "verification" of basic principles of science *and toward* an emphasis on the inductive development of a functional understanding of the principles of science through problem-solving performed by pupils under the guidance of the teacher.
2. *A trend away from* using interesting and practical technologies as the

central core of science courses *and toward* the use of these technologies as illustrations and applications of principles of science in everyday living.

3. *A movement away from* teacher demonstration *and toward* pupil experimentation and problem-solving.
4. *A trend away from* simple manipulations directed by detailed instructions and occupying a single class period *and toward* pupil-teacher planned experiments, the performance of which may require several days or weeks and for which apparatus must be left in position for the duration of the experiment.
5. *A trend away from* the requirement that all pupils in a science class perform the same experiments in the same period *and toward* the practice of using a variety of experiments and projects performed at the same time by individuals and small groups.
6. *A trend away from* instruction in basic science only for college-bound pupils *and toward* instruction to develop an understanding of basic science principles, concepts, and methods as a component of education for all pupils in an age dominated by science.
7. *Increased use* of science clubs, science fairs, and other supplementary activities to challenge and encourage the talented in science, and to provide opportunities for all interested students to perform experiments and carry on projects which cannot be done effectively during regular class time.
8. *Increased use* of closed-circuit and broadcast TV in science teaching, especially in connection with motivational and supplementary activities; and *increased emphasis* on planning facilities for the effective use of this medium by pupils and teachers and on designing different types of mock-ups and demonstration equipment for use on-camera and in follow-up learning situations.
9. *A trend toward* flexibility in design and construction of science facilities to permit change in room size and in the location of work surfaces, storage spaces, and teaching aids.
10. *Increased use* of audio-visual aids by small groups of pupils or even by individuals engaged in special projects rather than by entire classes at the same time.
11. *A trend toward* the extension of the science curriculum by the introduction of new units or courses such as nuclear physics, radio-active isotopes, antibiotics, and astrophysics which require more over-all space in the building as well as additional specialized spaces removed from the main school building.
12. *A trend toward* the homogeneous grouping of pupils particularly for the basic courses, including science, so that the talented students will be encouraged to progress at their own speed. The teachers assigned to the advanced groups are usually those who have a good background

in a broad range of science subject matter and can stimulate pupils to perform experiments and projects not feasible in classes which represent a wide range of abilities. Homogeneous grouping of pupils for science classes may mean that different types of facilities and equipment may be needed for each type of class, such as general, all-science laboratories for general classes, and specialized single-science laboratories for classes of talented pupils.[1]

ENROLMENTS IN SCIENCE

If the present emphasis on the need for improved science instruction and for more and better trained scientists has produced any desirable results, there should be evidence of increased enrolments in science both at the elementary and secondary levels even though science requirements for graduation from high school are not changed. Certainly if a number of states set up requirements of additional courses or sequences in science for graduation from high school, or if colleges reinstate such requirements as prerequisites for admission, there will be a marked increase in enrolments in science at the junior and senior high-school levels during the next few years. If the oft-stated aim of setting up an integrated program of science instruction throughout all the grades should result from the present emphasis, the total enrolment in science courses for any one year should approximate the total enrolment in public schools for that year. This will require a considerable increase in the space allocated to science instruction in both elementary and secondary schools and in the annual operating budgets for equipment and materials for science instruction.

Integrated Planning of Facilities

THE IMPORTANCE OF ADEQUATE FACILITIES

Ever since the introduction of science into the schools, the subject has been recognized as one requiring special facilities. Many of our

1. The following references may be consulted for more detailed information regarding the significance of the trends noted in the preceding paragraphs: Sam S. Blanc and Others, "Trends in Science Education," *Science Education,* XLII (March, 1958), 168–75; Sam. S. Blanc "Guideposts in Science Education—A Report on a Survey of Trends at the Elementary and Secondary Levels," *Science Teacher,* XXV (March, 1958), 82–83, 109–12; Stanley B. Brown, "Trends in Science Education—1953," *Science Teacher,* XXI (March, 1954), 84–85; Paul DeH. Hurd, "Mid-century Trends in Science Teaching" *California Journal of Secondary Education,* XXVIII (May, 1953), 244–50; Keith Smith, "Trends in Junior High General Science," *Science Teacher,* XXIII (March, 1956), 86–88.

high-school facilities today are stereotyped because they were copied originally from those provided in German universities and were designed primarily for lectures, demonstration, and prescribed experiments.[2] With the great emphasis today upon individualized instruction, it is necessary to plan science facilities which will stimulate and encourage the individual pupil to explore actively the world of science with the teacher as his guide. For the best teaching-learning experience, each facility must be designed in terms of its desired function and service.

BASIC PRINCIPLES AND PROCEDURES FOR PLANNING FACILITIES

After analyzing the philosophy of education of the school or school system and the contributions of science instruction to the total learning process at each school level, two important decisions should be agreed upon before selecting facilities for use in teaching science:

1. Determining the objectives of science instruction for each level, what the science curriculum should contain in the way of learning activities and experiences, and the elements of science which should be introduced at each level to attain these objectives.
2. Determining whether science will be taught as a separate subject or integrated with other subjects to form a core.

After these steps have been taken, the community resources outside the school should be surveyed to determine which of them can be used effectively in the science program. Facilities or resources necessary for the science program which are not available in the community will have to be provided in the school. In providing facilities, it should be kept constantly in mind that, besides the actual space for science instruction, adequate furniture, equipment, chemicals, supplies, and apparatus are essential. In addition, supplementary aids such as books, magazines, charts, records, films, film strips, slides, radio and television along with the proper equipment for use and storage of them are necessary. Many science projects will also require outdoor facilities.

In planning it is essential that each space and each piece of equipment be designed to be as functional and as adaptable as possible. This will permit modification in use from day to day as well as facili-

2. Aaron J. Ihde, "The Development of Scientific Laboratories," *Science Teacher*, XXIII (November, 1956) 325–27; Sidney Rosen, "A Century of High-School Science," *Science Teacher*, XXIII (November, 1956), 321–24.

tate revisions of the curriculum which are bound to occur. Giving a high priority to flexibility will result in a very minimum of fixed walls and built-in equipment.

For the guidance of the architect, it is necessary to describe the needs in terms of specific spaces, rooms, and equipment. The description should give the sizes of the different spaces needed; the types and shapes of spaces; the built-in requirements; the required services and their locations; the types, sizes, and probable arrangements of movable furniture and equipment; the storage requirements; and all special features necessary for the effective teaching of science at the level involved. These educational specifications should be in the form of a scrapbook of sketches, drawings, ideas, suggestions, pictures, and clippings. Their purpose is not to instruct the architect how to design the space but, rather, to acquaint him fully with the needs of the program for which the space is to be used.

PERSONNEL FOR PLANNING

If the foregoing procedures are followed, the entire faculty of a school should participate in the work. There is no activity or subject field in our schools which does not involve in some way phases of physical or biological science. The teachers should be divided for study purposes into grade or interest groups. Each group should have the advice of curriculum specialists as well as subject specialists. A final review of the plans should be made by a committee composed of an elementary-science specialist, a high-school science specialist, a specialist in child development, a high-school curriculum specialist, and a school-building specialist.

PLANNING AIDS FROM STATE DEPARTMENTS OF EDUCATION

A department of school plant services or its equivalent is organized in the state department of education in 37 states. Each of these divisions has one or more professional staff members qualified by training and experience to assist local school officials with problems of planning and equipping school buildings. In addition, the staffs of some state departments of education include specialists in science education as well as other specialists in curriculum who can give assistance to science supervisors or teachers with problems related to facilities, equipment, or instructional materials. Many of the states

have one or more official publications which discuss requirements or recommendations of the departments for science facilities in the public schools. Some of these publications describe floor plans or layouts for science departments. In addition, many states publish handbooks on school accreditation or courses of study which contain lists of science furniture and equipment.

PLANNING AIDS FROM FURNITURE AND EQUIPMENT MANUFACTURERS

Most of the leading manufacturers of science laboratory furniture and apparatus are members of the Scientific Apparatus Makers Association.[3] This association has a staff of consultants who provide information requested by school officials on the planning or equipping of science rooms in elementary and secondary schools.

In addition, most of the manufacturers of science laboratory furniture have staffs of engineering and educational specialists who provide similar free services on request from school officials.

At least two manufacturers[4] have produced "planning kits" consisting of scaled floor plans and scaled models of demonstration tables, storage cabinets, cases, desks, chairs, and other items of furniture which can be used to develop a variety of layouts of equipment for science laboratories and combined laboratory classrooms. In addition, most of the larger manufacturing companies have published floor plans and equipment layouts for different types of laboratories and combined laboratory-classrooms.

PLANNING AIDS FROM LOCAL RESOURCE INDIVIDUALS AND ORGANIZATIONS

In addition to the sources discussed in the preceding section, every community has access to organizations or individuals who are familiar with local problems and who can render assistance in planning science facilities. Some persons who may be able to give valuable assistance are:

1. School planning specialists who are staff members of schools of education, architecture, or engineering of state universities and colleges.

3. Scientific Apparatus Makers Association, 20 North Wacker Drive, Chicago 6, Illinois. Executive Vice President, Kenneth V. Anderson.

4. Fisher Scientific Company, 717 Forbes St., Pittsburgh 19, Pennsylvania, and W. M. Welch Scientific Co., 1515 Sedgwick St., Chicago 10, Illinois.

2. Science subject-matter specialists in colleges and universities who are responsible for the education and training of science teachers and are familiar with local needs and resources.
3. Members of professional scientific or technical associations such as the Academy of Science, the American Chemical Society, and the American Institute of Architects.
4. Individuals who were formerly science teachers at the high-school or college level, but who have retired from teaching, or have taken positions in industry.

In view of the critical need for improving instruction in science and mathematics, many of these individuals would welcome the opportunity to render service which would result in improving school science facilities. Many of them should be encouraged and invited to serve, along with teachers and planning specialists, on committees organized to recommend facilities.

Facilities for Science Teaching at Different Levels

FACILITIES FOR THE ELEMENTARY SCHOOL

The necessary facilities for a good elementary-school science program need not be either elaborate or unduly expensive, but they should provide opportunity for experiences in a wide variety of science topics. Most children of elementary-school age are not conscious of the distinctions among various fields of science, nor should they be. But they are tremendously interested in many aspects of their environment, and the materials available to them in all classrooms where science is taught should reflect this breadth of interest.

Teaching Space. Among desirable facilities for the elementary classroom, that of adequate space seems to be paramount. Children need space to work; space to read; space to experiment; and, particularly, space in which to set up and leave occasional long-term projects or exhibits.

Work Counter. Many existing classrooms can be equipped with a counter running along one or two sides of the room, and of proper height to permit children to work to good advantage. Storage cabinets provided under the counter (movable cabinets are now available) can make this a most useful work and storage facility.

Electric Outlets. Duplex electric outlets at convenient intervals along the work bench, and also at the front and back of the room,

will make it possible to operate electric appliances, apparatus, and projection equipment and to perform many experiments.

Running Water. A great many science demonstrations and experiments involve the use of water. Accordingly, at least one sink with running water should be placed in each room in which science is taught.

Gas. Gas outlets are of less importance, though they are convenient at times. There will be very few times in the elementary classroom when the heat from a good electric hot plate or an alcohol lamp will not suffice. If there is gas, any use of it should be under the teacher's supervision.

Storage Space. Lack of storage space can be almost as much of a problem as lack of work space. Adequate closets for keeping materials which are not being used are needed in each room. In addition, a central storage space in each school for material which is used only occasionally is most desirable. Laboratory carts or movable demonstration tables will facilitate the transporting of materials from the central storage place to the classroom and back again.

Display Case. The use of corridor cases for the display of projects, collections, and matters of scientific interest to the whole school has sometimes been very successful. If this device is used, someone should be made responsible for keeping the exhibits clean and attractive and for changing them often.

Bulletin Boards. Classrooms need adequate bulletin board space for display of posters, motivational material, and items of current interest. Inexpensive and effective bulletin boards may be made out of soft wallboard. Materials displayed on bulletin boards should be changed often.

Darkening Shades. The ideal classrooom will have provision for effectively darkening the room, not only for the projection of films and film slides but also for conducting those science demonstrations or experiments which are most effective in a darkened room.

Work Space. A place is needed where children may construct science projects for display or other purposes. A sturdy table makes a fine workbench, particularly if it is equipped with a vise which can be used for holding both wood and metal. A set of hand tools for working with wood and metal should be provided in each room or made available in a convenient location in the building.

FACILITIES FOR THE SECONDARY SCHOOL

While certain science subjects taught at the secondary level require special facilities for maximum learning, there are many needs which are common to all areas of high-school science. The following recommendations should be taken into account in the preliminary planning of all high-school science classrooms.

Location. Science rooms should be placed together in a science wing to permit sharing of common teaching materials. Biology and general science rooms are best located with a southern or eastern exposure to permit optimum lighting of plant-growth areas.

Flexibility. Rooms should be adaptable to a variety of science subjects and teaching methods. Essentially, this indicates a minimum of fixed equipment and the placement of utility lines along the sides or in one section of the room. Movable laboratory furniture is recommended whenever its use is feasible.

Space Requirements. A minimum of 30 to 35 square feet of classroom area per student (exclusive of storage facilities) is recommended. An additional fifteen square feet per student is recommended for storage facilities.

Special Activity Provisions. Facilities should provide areas where individual experiments and projects may be carried on and the unfinished projects stored safely for extended periods of time. There should be areas which are equipped with the proper tools and supplies in which science apparatus may be constructed and repaired. Facilities should permit student use of published and printed materials.

Furniture. Furniture should be adaptable to class, small group, and individual work. Work surfaces should be resistant to chemicals. Colors other than black are now available. They are pleasing to the eye and eliminate some of the undesirable light contrast between the work surface and paper or books. A demonstration table, 37 inches high and equipped with service utilities, is essential.

Audio-visual Aids. Rooms should be equipped with a projection screen placed in a permanent location. To simplify "plugging in," the speaker-cable conduit should extend the length of the room. Darkening facilities, chalkboards, tackboards, display cases (one vissible from the corridor), and chart rails are minimum requirements.

Safety. Lines for gas, water, and electricity for the student work areas should have master shut-off controls. Adequate fuses or circuit breakers should be provided on all electrical lines, and all lines and conduits should be grounded. Forced ventilation in storerooms, locked storage space for dangerous chemicals, laboratory first-aid kits, and an approved fire extinguisher should be provided.

Supervision. To increase the amount of visual control by the teacher, rooms should be (*a*) square rather than long and narrow, and (*b*) should have glass vision strips between the classroom and storage-preparation areas or offices.

Traffic Movement. Various learning centers in the room can be made accessible with a minimum of disturbance by providing sufficient "aisle" space, strategic distribution of storage centers about the room, and by devoting particular attention to traffic movement to and from the check-out point for supplies.

Lighting. Glare on boards and work surfaces, as well as undesirable light contrasts between chalkboards and walls and between table tops and "tasks," should be eliminated. A minimum illumination of 30 foot-candles on work areas reduces eyestrain. Spot lighting of the demonstration table increases the visibility of demonstrations. Special individual lighting of work spaces may be necessary for some difficult visual tasks such as dissection, reading instrument dials, and using a microscope.

Maintenance. Plumbing, especially sink traps, should be easily accessible and should be resistant to chemical action and chipping. Tempered water should be available at least at the demonstration desk and in the storage-preparation area. Waste receptacles should be located so as to be out of traffic. Floors and table surfaces should be of material that is easily cleaned and resistant to chemicals and to marring.

Architectural Treatment. A minimum of considerations for well-designed science rooms include proper lighting, good ventilation, maneuverability and pleasing color. Work tables, walls, floors, and draperies no longer need to be black or dull to be effective. Special attention should be given to making science classrooms and laboratories attractive areas for study.

Auxiliary Science Rooms. a) Storage-preparation rooms—Areas for storage and preparation are generally narrow, short, inaccessible,

overcrowded, and unattractive spaces. Rather than just a stockroom, the preparation room should be a place where a limited number of students can engage in junior research and can acquire special manipulation skills. The storage-preparation area should also provide space for the instructor to carry on research and to prepare and leave, undisturbed, the materials to be used in the day's classes. Forced ventilation, adequate lighting, gas, water, electricity, and work surfaces of generous size are minimum requirements. Storage facilities, which may extend to the ceiling if a movable ladder is provided, should include movable units, adjustable shelves, and a wide variety of bins, drawers, and cabinets. There should be ready access to preparation areas from adjacent corridors in order to prevent interruption of classes. Doors should be wide enough to permit easy passage of laboratory trucks and carts. Floors under doors should be without thresholds to permit movement of trucks without lifting.

b) *Darkroom*—Minimum requirements include a double-drainboard sink, hot and cold water, electrical outlets in the walls above work areas, light traps at entrances, ventilation and temperature controls, utility tables, drawers and cabinets, safety light switches, and signal lights to indicate that the darkroom is in use.

c) *Science teachers' office*—An individual office with corridor and classroom entrances is highly desirable. A general room for teachers, located near the science suite, is satisfactory. The office area may also be in the storage-preparation area. Minimum requirements for the office area include desk, files, and bookshelves, and arrangements that provide some privacy with visual control of the classroom.

FACILITIES FOR THE JUNIOR HIGH SCHOOL AND SPECIALIZED SCIENCES

The Junior High School. General science is becoming more and more a course in which emphasis is placed on exploring science; in which the discussion method is more commonly used than the lecture; and in which individual laboratory work, projects, and reports have a major place in instruction.

In line with these trends, junior high school science rooms should be more than just additional classrooms. They should be multipurpose science rooms that meet minimum requirements with respect to space, facilities, and arrangements. Movable two-place student

tables are preferred as the basic furniture. Work counters along the windows, supplied with gas, electricity, water, and with storage cabinets underneath, are desirable features.

The Specialized Sciences. In addition to the recommendations for all-science rooms, the following should be considered in designing rooms for particular science fields.

a) *Biology room*—Special provisions should be made for plant and animal growth areas. Movable aquaria tables and plant germination beds are useful when separate plant and animal rooms are not available. A lean-to, glassed-in growing room adjacent to the biology room provides an excellent solution to the problem of housing both plants and animals. Plant benches, similar to those in modern greenhouses, provide stands on which movable plant boxes may be placed. Animal benches may be double-tiered metal stands sloped for drainage. Floors should be concrete, and sloped to drains. Storage facilities for soil, peat moss, and sand, accessible from both inside and outside the room, should be provided. If possible, drawers and bins of various sizes for tools and flower pots should be provided. The electric wiring should be carried in a rigid conduit with marine-type fixtures. Temperature- and humidity-control apparatus, as well as ventilation by means of movable side sash and a ridge sash, should be provided.

Dust-proof cases for microscopes and other optical equipment should be provided in the room. To facilitate traffic flow, the storage of microscopes and tote trays should be divided between at least two separated areas in the room.

The storage-preparation area should be equipped with a refrigerator and a vermin-proof case for specimen storage.

b) *Chemistry room*—Features of facilities and equipment which are particularly desirable for effective chemistry teaching are:

The chemical supply table, the preparation table, and the shelves and cabinets for large bottled chemicals should have a wooden ridge *surrounding* the table or shelf. The ridge should be high enough to provide a basin for ordinary amounts of spilled chemicals.

A special case or shelf for glass tubing should be provided.

All surfaces in the room—sinks, sewer lines, floors, and working surfaces—should be of materials resistant to corrosion, tarnish, and moisture damage.

A convenient place should be planned for a water still or ion-exchange apparatus and for a dispenser table or stand for distilled water.

Special storage facilities, located at the floor level, should be provided for large bottles of liquid chemicals.

At least one metal-lined cabinet should be provided for highly volatile chemicals.

A special storage area for tote trays should be planned if they are to be used.

Traffic control in a room where chemicals are handled is of utmost importance. To reduce hazards, special consideration should be given to the planning of traffic lanes to and from the supply table, reagent case, balance table, fume hood, tote-tray cabinet, and preparation room.

In addition to these suggestions, it is recommended that, to promote safety and improve visual control, chemical laboratory desks be designed to eliminate the possibility of storing chemicals and equipment on shelves above the laboratory tables.

In larger schools consideration should be given to the possibility that in the next few years new units and learning experiences in nuclear physics will be added to the course in chemistry. This addition will require highly specialized facilities for which expert planning will be required.

c) *Physics and physical-science rooms*—Recommendations relating to the facilities and equipment for physics rooms are as follows:

A source of both alternating and direct current with polarized outlets should be provided. If there is to be a motor-generator and a panel, space for them should be planned at the time the room is designed. The panel should be backed with glass and located where it can serve as a facility and as an instructional device. A bank of storage batteries providing up to 24 volts or Lab-Volt units in each table may be preferred to the motor-generator.

Storage cabinets for physics equipment should be located where chemical fumes will not cause corrosion. Storage space should be of sufficient size to house heavy, oversized, and irregular-shaped equipment. Cases for valuable and delicate equipment should be provided with locks.

Demountable, vertical and cross rods on pupil and demonstration tables are preferred to permanent placements.

A direct entrance to the photographic darkroom should be accessible from the physics room.

FACILITIES FOR TRAINING SCIENCE TEACHERS

Elementary. By and large, a discussion of the training of science teachers for the elementary schools boils down to a discussion of the science training of the general classroom teacher. The kinds of facili-

ties needed depend to some extent on the level of science and variety of science courses in the teacher-training curriculum. If the prospective teacher has had an adequate variety of science courses, they should try out, in the *teacher-training* science laboratory, a wide variety of the kinds of activities recommended for children. The facilities recommended for such a laboratory would simply be an enlargement of the facilities recommended for the good elementary classroom in which science is taught.

However, in many cases, particularly in a four-year curriculum, teachers do not get a sufficient variety of science experiences to equip them to adequately teach elementary science. This means that courses in the teaching of science should be combinations of subject matter and "method."

For this latter type of course, which must concern itself at least in part with filling gaps in the prospective teacher's content background, somewhat more elaborate specialized facilities, similar to those recommended for teachers of secondary science, should be provided.

Secondary. "We learn by doing" is a maxim often quoted but infrequently heeded in teacher-training institutions. Prospective teachers of secondary science need an opportunity to try out teaching procedures, instructional devices, and materials to be used with adolescents in classrooms and laboratories.

These teachers will be more skilful if they have instruction and laboratory experience in the use, manipulation, building, and maintenance of the facilities and materials required for science teaching. Such experiences are provided most effectively in a professional laboratory for teachers.

The professional laboratory may be housed in a science department or in the education department. A recent committee report[5] makes several recommendations relating to the science teachers' laboratory. Among these recommendations are the following:

1. Materials should be provided to enable future teachers to engage in experimentation on a scope sufficiently broad to prepare them to direct appropriate learning activities of the pupils they are to teach.
2. The facilities should provide for construction, repair, designing, and building of apparatus.

5. *School Facilities for Science Instruction*, pp. 201–7. Washington, D.C.: National Science Teachers Association, 1954.

3. There should be adequate gas, electricity, and water facilities throughout the laboratory.
4. There should be adequate storage, library, and audio-visual resources provided.
5. The laboratory should provide for various instructional centers within the laboratory. These should include such general centers as: a printed reference material center; an audio-visual center supplied with projectors, cameras, screens, and recording devices; materials for preparing tackboard displays and making mock-ups; a construction center equipped with tools for wood and metal working; and a photographic center or darkroom. In addition to the general centers, there may also be science subject-matter centers. These should include an elementary-science center equipped with simple equipment used in elementary schools, a biological-science center including plant and animal growth areas, a chemistry center, a physical-science center including an electrical center, and an earth-science center.

Location of work surfaces and services around the perimeter of the room is recommended rather than fixed laboratory desks in the center of the room for there will be times when it is desirable to clear the entire floor space in order to set up experiments or demonstrations. For this reason light-weight stackable furniture is desirable. Certain outdoor facilities, at least enough space to plant some experimental plots for study, should be provided.

The instructor in such a course should be provided with a separate office which can be used as a student conference room and preparation room. He will need ample filing space for "free" and other teaching materials, such as pictures and charts, as well as a place in which special apparatus may be kept safely.

SOME NEW DEMANDS ON FACILITIES

Elementary. It is difficult to see what *new* demands will be placed on facilities for teaching elementary science or for training elementary science teachers. Continuing public interest in "teaching more science" and improving science instruction at all levels of the schools will result, eventually, in the provision of the necessary facilities and equipment for science instruction in all elementary classrooms.

Recognition of the fact that science instruction should begin in the kindergarten and that all elementary-school teachers should have some training in science will lead inevitably to demands on teacher-training institutions to develop broad programs in science education

for all elementary teachers and to provide adequate facilities and equipment for carrying on this training.

The programs and facilities will be designed to meet the needs of two types of teachers: prospective teachers who are preparing for elementary positions, and experienced elementary teachers who return to higher institutions to improve their backgrounds in science subject matter and their methods of teaching it.

Secondary. For many years teachers have faced the challenge of transmitting to their students both the product and the process of scientific discovery. They have enjoyed considerable success in transmitting the product; less in teaching the process. Increased emphasis upon the latter is creating new demands on facilities for teaching science at the secondary level.

There are those who believe that the only way children can actually be made to understand the process or methods of science is to encourage them to take their own excursions into scientific discovery, under the guidance of the teacher. Classrooms and laboratories in which boys and girls are to learn science through experiments and projects which are pupil initiated must be more adaptable and must include many tools and working facilities not traditionally provided in high-school laboratories.

Some people believe that the best way for boys and girls to grasp the feel of the scientist at work is to have them re-enact classical experiments. Again, this point of view will require that certain new items be added to the materials provided for traditional science instruction.

The out-of-school environment of boys and girls today provides them with many sophisticated experiences which illustrate and make application of scientific principles. It is becoming more and more difficult to arouse the enthusiastic response of boys and girls to a piece of laboratory equipment which applies a principle in a less meaningful fashion than do rockets, jet planes, television receivers, or polio vaccines with which they are already familiar. This suggests that those who assume responsibility for the laboratory exercises in our public schools must develop new exercises and encourage the design of new equipment to clarify difficult and perplexing principles and concepts.

Finally, it is now generally accepted that students should be taken

into the laboratory whenever individual or small-group laboratory work is the most effective means to attain the learning goal that is sought. Acceptance of this point of view will require that adequate laboratory facilities exist in each school and that they be reasonably available at all times rather than on a highly scheduled one- or two-period-per-week basis.

EVALUATING THE ADEQUACY OF FACILITIES

Many check lists and score cards have been used for evaluating science facilities. Most of them deal solely with space, services, and equipment. Although these are important, their adequacy can be judged only in terms of the curriculum to be followed and the learning activities to be engaged in by pupils. There are some more nebulous features which can be evaluated only by studying specific environments. Some evaluating criteria which are designed in terms of the function of the facilities and their physical and psychological impact upon the pupils are the following:

1. Do the facilities meet the demands of the curriculum in terms of space, equipment, services, and learning aids?
2. Do the facilities stimulate individual exploration?
3. Do the facilities help to develop a sense of responsibility?
4. Do the facilities permit an intimacy and feeling of identification with the chosen project?
5. Do the facilities permit challenges to which the pupils may successfully respond?
6. Do the facilities permit the use of aids to learning without undue waste of time or lost motion?
7. Are the facilities flexible enough to meet changes in the program?

Careful application of these criteria when planning new science facilities or remodeling existing ones will result in better teaching environments for science.

Equipment for Science-Teaching

THE PLACE AND FUNCTION OF LABORATORY TEACHING

Elementary. All science-teaching is, to some extent, laboratory teaching. Children (and grownups, too), when they get the chance, seem naturally to want to try out things. They not only want to observe the phenomena they read about but they want to try to find for themselves answers to at least some of their problems. Moreover,

the experiment—"asking a question of nature"—lies at the very heart of scientific method, and, as such, genuine experimentation at the elementary level offers great opportunities for teaching scientific thinking and for developing scientific attitudes.

Although demonstrations are, to some persons, in bad repute, due probably to their misuse as substitutes for experimentation, carefully chosen demonstrations do offer opportunities for enrichment of the experience for children. Every classroom where science is taught should be a place for experimentation. Therefore, since teachers are likely to teach the way they are taught, every science classroom in which teachers are being trained should be a laboratory.

Secondary. Each laboratory exercise should have a clear-cut educational purpose. It may, for example: (*a*) add reality to the textbook material, (*b*) develop firsthand familiarity with the tools, materials, or techniques of science, (*c*) allow the student to demonstrate to himself something that he already knows to be true, (*d*) give the student an opportunity to pit his laboratory skills "against par" in seeking an experimental answer, or (*e*) create opportunities wherein the student predicts events or circumstances and then designs experiments to test the accuracy of his predictions. The most cogent reason for providing adequate laboratory facilities derives from the importance of the last of these purposes.

TYPES OF LABORATORY TEACHING—PROCEDURES AND EQUIPMENT NEEDED

Elementary Level. The idea that every classroom needs to be a place of experimentation has implications for teaching procedures and for equipment.

The selection of equipment should be based on the learning activities to be engaged in by pupils and on the level of competency of the pupils involved. Elementary science is, primarily, a study of the environment; therefore, in so far as possible, the materials used should be those derived from the environment, for example, common household chemicals, tools, and appliances; magnets, dry cells, and bulbs; local rocks and minerals; and local plants and animals. Hand tools for simple construction and lumber, taken perhaps from wooden crates, are needed. Simple equipment such as garden trowels, boxes for specimens, and hand lenses are useful for field trips.

Specialized equipment should be used judiciously in the elementary classroom since it is difficult, if not impossible, for children of elementary-school age to see the connection between highly specialized equipment suitable for a high-school or college laboratory and anything in their own environment.

Secondary Level. In modern science-teaching at the junior and senior high school levels it is difficult to distinguish sharply between teaching procedures used in class work and those used in laboratory work, since laboratory activities are used in the development of a lesson at any time that they can contribute effectively to class work. The combined laboratory-classroom, which has become the most common type in our secondary schools, was developed primarily to facilitate such an exchange of procedures.

There is no general agreement among science educators as to the best method for organizing science instruction. Highly successful teachers are using the "unit method"; others equally successful are using the "project method" or the "problems method." There is general agreement, however, on two points: (*a*) There is no one method of instruction that can be considered best for all learning situations in science, and (*b*) the science room should be a place where problem-solving activities of various types can be carried on. Some problems are solved primarily by experimentation; some by appeal to authority; some by discussion; some by visualizing; and some by listening to teacher explanations or watching teacher and pupil demonstrations. The teacher's techniques and the learning activities to be engaged in by pupils should furnish guidelines for determining types and amounts of equipment to be made available.

FACTORS AFFECTING THE NEED FOR EQUIPMENT

Elementary. Important factors affecting the need for equipment are: (*a*) the increased emphasis on and national concern for science, and (*b*) the differences which exist among communities. As to the first, it is increasingly recognized that our chief national resource may well be our trained scientists and technologists. With this realization comes another: that those with special talents in science must be identified as early as possible and encouraged as much as possible. This argues for a rich school environment for all, so that each pupil may develop his talents, interests, and abilities to the fullest.

Communities have special needs and problems. A rural school has less need for special equipment for growing plants than has an urban school simply because such facilities are already present in the rural community. Children of a community supported largely by chemical manufacturing have a special interest in the scientific principles underlying the processes by which the community makes its living. All such considerations affect the nature of the science program and the kind of equipment needed to make it effective.

Secondary. Probably the greatest factor in determining the need for new laboratory equipment or facilities in the secondary school is the need to help teachers keep abreast of modern practices and current topics. The scientific enterprise is evolving at such a rapid rate that many new discoveries, inventions, and ideas will be neglected unless the turnover of textbooks and laboratory manuals can be speeded up or satisfactory substitutes found. University, government, and industrial scientists are actively helping teachers design new laboratory exercises which will keep the school program in gear with modern developments.

GUIDING PRINCIPLES FOR SELECTING FURNITURE AND EQUIPMENT

It can be anticipated that, as the volume of construction of school buildings continues to rise, many science teachers will be faced with the responsibility for recommending the purchase of furniture and equipment to school officials and school boards.

There are some basic principles that are important in the selection of general school furniture that can be applied to furniture for science rooms.[6] The principles are as follows:

1. It must be safe. It should have no sharp corners or metal edges that can cause injury.
2. It should be well built and sturdy since science furniture is subject to heavy and sometimes rough usage.
3. Except for items requiring fixed services, it should be readily movable to permit easy regrouping in the room.
4. It should be designed to encourage good posture and to facilitate the proper development of manipulative and other skills.
5. It should have lines and colors that are pleasing to the eye.

6. Adapted from Edwin E. Niccolls, "The School Furniture Problem," *American School Board Journal*, CXXII (December, 1951), 41–43.

6. Materials, methods of construction, and design should reflect an analysis of the functions to be served, such as experimentation, demonstration, reading, storage, and display, rather than a preconception gained from college installations or conventional school provisions.
7. It should be adaptable to whole class, small group, and individual science work.

In general, standard manufactured furniture is more economical and more effective than that which is custom-made or locally built.

The specific types of furniture and equipment to be provided in each room, especially those that are built-in or fixed, should be determined before the architect's final drawings are made. This is essential so that any modifications or adjustments which are needed to accommodate the furniture and equipment selected can be made before the building is constructed. Attention should be given to the location of utility lines to pupil and teacher work stations, to size of entrances into storerooms, to placement of display and storage cabinets, and to location of heating and ventilating services in relation to room and storage facilities. Alterations in the building proper and in the service facilities are very expensive if they have to be made after the furniture and equipment are delivered for installation.

One of the most important tasks of the science teacher is the preparation of lists of equipment and supplies for the science courses which he is teaching. This is especially true for those who are doing creative, developmental teaching, and introducing modern concepts and experiences into their science courses. Selecting far in advance of use the items which are needed for specific learning activities outlined in an official course of study is a difficult task; but selecting for those activities, experiments, and demonstrations which arise spontaneously in developmental teaching is more difficult, since standard lists of equipment are inadequate for this purpose.

The curriculum guides or courses of study should furnish guidelines to the formulation of basic lists of needed equipment and supplies, but the teacher who will use the materials should be given the major responsibility for selecting equipment and supplies. Each teacher should be given considerable leeway in modifying the list or in devising supplemental lists of special items to fit the purposes of the courses he is to teach and the potential of the pupils involved.

SECURING AND MANAGING FUNDS FOR EQUIPMENT

In the past, due to rising or unanticipated construction costs, many new buildings have been equipped with old furniture and equipment, and essential or specialized built-in equipment has not been purchased because the extra construction costs were taken out of the equipment budget. This has had an adverse effect on the quality and effectiveness of the science program offered in these schools. All individuals who have an interest in improving science instruction have a responsibility to see that adequate provisions are made for science facilities in the budget for a new school building and that amounts budgeted for these facilities are actually used to provide them.

In the annual operating budget of every school in which science is offered there should be a definite allotment for science equipment and supplies. The allotment should be sufficient to take care of not only normal replacement of broken and used-up items but also the purchase of new and more effective items as they become available or as they are needed for new problems, units, or courses. In those schools where there is little or no equipment or instructional materials, the initial budget should be larger than normal for a few years so that adequate stocks of equipment can be built up.

In addition, a substantial petty cash fund should be provided, either for use by the science department or by individual science teachers. In elementary and small high schools, this fund should be administered through the principal's office; in large schools, through the head of the science department. It should be used for purchasing the many incidentals for experiments, demonstrations, and projects, the need for which cannot be anticipated when the annual requisitions for science equipment and supplies are prepared.

PROCEDURES FOR SELECTING AND PURCHASING EQUIPMENT

The major responsibility for the selection of science equipment should rest with the users, that is, the science teachers, and not with the superintendent or the school business official as is so often the case. The recommendations of the teacher should clear through the established levels of administration within the system and should be changed only when budgetary or other carefully weighed considerations indicate that a change is necessary. This places responsibility

on the science teacher to select and recommend only those items which are optimally effective and only those quantities which are necessary for the learning activities of the pupils involved.

The actual purchasing of equipment should be done by the school official who is trained and authorized to do all purchasing for the school rather than by the science teacher. The only exceptions to this rule would be the purchase of incidentals from a petty cash fund or of small items of equipment and supplies for use by teacher-sponsored science clubs or by individual students in connection with class projects or activities.

INVENTORYING, TESTING, STORING, AND CARING FOR EQUIPMENT

Efficient use of equipment and supplies for science instruction, especially if more than one teacher is involved, requires that an accurate, up-to-date, cumulative inventory should be kept of all furniture, equipment, and major items of supply in the science department. An economical way of doing this is to set up an integrated system of card-cataloguing and storage locations. One set of cards should be used for nonexpendable furniture and equipment, and another for major items of expendable supplies.

The inventory system for nonexpendable items of furniture and equipment should be set up with a separate card for each item. Each card should be designed to contain the following minimum information: name, catalogue illustration, cost, and usage-rate of the item; location in storage; date and purchase order numbers for the item; number of units on hand; condition; and withdrawals for breakage, loan, or other specified reasons.

A similar system should be set up for expendable supplies. In addition, a unified system for labeling storage cabinets, cases, bins, and drawers throughout the science department should be set up, and the card-cataloguing system should be closely integrated with the storage system.

THE ROLE OF IMPROVISED EQUIPMENT

There are many occasions when ready-made equipment is not available for experiments and demonstrations and it is necessary for pupils to improvise the needed equipment. The making of such items may provide valuable training in science, particularly if creativity in

designing a piece of apparatus to illustrate a science principle or concept is involved. However, it is important to remember that considerable time can be wasted in construction activities that merely provide training in manual dexterity and contribute little or nothing to the development of scientific skills or understandings. Before such projects are undertaken, the teacher should determine if the science learnings which can be expected to develop from them will justify the time and effort expended; if they do not, other ways of developing the desired learnings should be planned.

There are many occasions when pupils at all levels should observe actual scientific and technical instruments and apparatus in operation or use them in experiments or projects. It is doubtful if the use of improvised or make-shift devices can be justified when suitable operating devices and instruments are readily available.

TEACHER TIME FOR LABORATORY DUTIES

If the trend in science instruction noted in the better schools continues, that is, an increasing emphasis on pupil planning and performance of experiments to determine the principles which are actually inherent in a problem under investigation, it is reasonable to assume that a greater variety of apparatus, equipment, and materials will be required. This in turn will mean that the science teacher will need much more time to anticipate and to plan for pupils' experiments, to secure needed equipment and supplies, to set up and supervise procedures for issuing and distributing needed items from the stockroom, and to repair broken items. Although some of these are housekeeping "chores," they have to be done in order to keep an effective science program going. They are now being done by the science teacher, in some cases during free periods which have been set aside for this purpose; in far too many instances, however, by conscientious teachers on their own time during evenings, weekends, or vacations.

It may be that the success of some recent experiments with teacher aides in elementary schools will indicate the value of laboratory assistants who could relieve the science teachers of such chores and enable them to devote all their time and energies to teaching.

Special Problems of Facilities and Equipment

PROVIDING FOR SCIENCE INSTRUCTION IN BUILDINGS WITH INADEQUATE FACILITIES

Elementary. The problem of inadequate buildings, so far as facilities go, is less acute at the elementary than at the secondary level. The chief problem, as indicated previously, is one of space, but the problem of the overcrowded schoolroom, crucial as it is, is outside the scope of this yearbook.

New furniture and blackout shades may be installed even in old buildings. The provision of electric outlets is relatively simple. Gas for heating is generally unnecessary, and if gas heat must occasionally be used, portable propane cylinders can supply it. Storage closets may sometimes be built out of unused cloakrooms.

Secondary. In the past, remodeling of regular secondary-school classrooms into laboratory-classrooms has posed some difficult problems. The available furniture, consisting of fixed laboratory tables with services, was designed to be installed in rows in the center of the room. Remodeling the room and providing the services to these tables was an expensive undertaking. However, during the past five years all the leading manufacturers of science laboratory furniture have developed new lines consisting of wall counters, pupil-work tables, and teacher-demonstration tables which can be installed around the perimeter of the room or in islands in sections of the room. The service lines to these units can be run along the corridor wall or the outside wall of the room, eliminating expensive runs through the floor to the center of the room. With these units it is possible to remodel regular classrooms into modern, functional laboratory-classrooms with a minimum of expense.

For those schools which cannot afford the units described in foregoing paragraphs, there are now available movable laboratory demonstration carts. These are equipped with water and bottled gas and provided with an electric cord and duplex outlets which can be plugged into the regular wall outlets. One of these trucks can be wheeled into a regular classroom and used as a teacher-demonstration table or as a pupil-work center. Thus, at relatively small cost, any regular classroom can be transformed into a room in which science

experiments and demonstrations can be performed by the teacher or by pupils working individually or in small groups.

Movable storage cabinets and tote-tray cabinets are also available to provide storage space for science equipment and supplies in the classroom or in smaller rooms which can be converted for this purpose.

FACILITIES AND EQUIPMENT FOR NEW EMPHASIS

Closed-Circuit Television and Related Communications Media. Probably no other single development within the past quarter-century has the potentiality for making science-teaching more effective and challenging than the use of closed-circuit television.

Teaching by closed-circuit television is considered by many to be far in the future for the average school system. However, at least a hundred television-teaching projects are currently known to be in operation in universities, colleges, and public schools and from 60 to 70 other public school systems are known to be planning such projects.

From experiences already gained in these projects, it appears that it is possible to teach many aspects and some types of science lessons far more effectively than it can be done by conventional methods, except perhaps, that of individual pupil experimentation.

By means of television, a microscope slide can be examined, a demonstration dissection can be followed step by step, the moving parts of a model or piece of apparatus can be shown, or a chemical reaction can be observed by an entire class, by a number of different classes in the same school, or even in widely separated schools if they are connected by coaxial cable with the originating studio.

It has also been discovered that the role of the science teacher is not "down graded" in teaching by television but, rather, that it has been enhanced, the teacher's effectiveness being considerably increased. Class discussions have been improved and even the laboratory work undertaken spontaneously by the pupils has been expanded in scope as a result of the motivational impact of the suggestions or problems growing out of television presentations. In some cases this has made it necessary to expand the size of the science laboratories, and to add many new types of equipment for pupil use.

Many supplementary aids and enrichment materials used in con-

ventional science-teaching, such as slides, motion pictures, still pictures, and models, are used extensively in television teaching, and many new types of "visuals" have been developed for use on-camera. Moreover, since television can make any visual aid simultaneously available to all class groups within a school or school system, funds available for the purchase of such materials can now be invested in one copy of each and the money saved made available for the purchase of different materials. Even more significant, it is not necessary to darken the average classroom for viewing materials projected on television or to provide projectors or viewing screens in each classroom.

Implications for Planning Science Facilities and Equipment—Planners of school buildings should bear in mind that well within the useful life of school buildings now under construction, teaching by closed-circuit television can be expected to become general in most areas of instruction and particularly in science. Specific provision for the essential facilities should be incorporated in the building plans.

Assuming that it is intended to incorporate provisions for closed-circuit television into the plans for a new school plant, two items of caution are in order. *First*, it will normally be advisable to employ professionally qualified assistance to help translate local curriculum policies and instructional practices into procurement specifications for closed-circuit TV facilities and their installation and for supervising the actual installation. *Second*, considering that closed-circuit system engineering involves skills and judgments somewhat beyond the experience of the typical school architect and building contractor, it is recommended that they seek the advice of an expert in this field.

Atomic Energy, Antibiotics, and Astrophysics. Although these relatively new topics have been only recently introduced into the curriculum, individual science teachers throughout the country have had considerable experience with them. The results of these experiences are recorded in articles published in professional journals for science teachers. If it is planned to incorporate these topics into the science curriculum, specialized assistance in planning the facilities for them should be obtained since most of the school architects or plant-planning specialists have had little or no experience in developing facilities for teaching these topics.

FACILITIES AND EQUIPMENT FOR SUPPLEMENTING SCIENCE ACTIVITIES

Provisions should be made for conducting science clubs and science fairs and for using outdoor areas such as nature trails, farms, forests, and preserves where children may observe living things in their natural habitats rather than merely seeing pictures of them or reading about them in books.

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CHAPTER XIV

The Education of the Science Teacher

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Introduction

As perhaps never before in history, the education of the person who has direct responsibility for the teaching of science in our schools has come under the review of our citizenry. Very appropriately, parents, government officials, scientists, and engineers have joined with the professional educators in efforts to determine the basic problems of science and to find means of providing a more adequate education for those who are to become science teachers. Many organizations, agencies, and institutions have been involved in these efforts. Among these are colleges of education, colleges of the arts or of the sciences, certification and accreditation agencies, professional and scientific societies, and numerous agencies of government. These forces, in turn, have been joined by local groups in all regions of our nation. Tentative steps have been taken, and experimental programs of various types have emerged. Experimentation is necessary because, in the education of teachers, research is essential to fundamental advances.

Science in the General Education of Teachers

Science is the pursuit of knowledge through direct investigation. Seeking knowledge is also fundamental in education, yet many persons, otherwise well educated, have failed to acquire a basic understanding of science. There are several reasons why science in education has traditionally been neglected. These include the conflict in point of view between experimentation and classical authority, inad-

equate preparation of teachers, and poor communication on the part of scientists who have stressed the technical aspects of their work in a way that has made it appear overwhelming to the uninitiated. As a result of poor instruction, false impressions of science are common. Science has become identified in the public mind with dramatic innovations and often is considered equivalent to rockets, atomic bombs, and new mechanical devices for common convenience. Therefore, when changes are suggested in school curriculums or when other educational issues arise, many individuals express opposition to science and even to the pursuit of truth.

The curriculum for the professional preparation of teachers, as for the education of others, should reflect in all its parts, history, philosophy, literature, the arts, that is, the impact of science on human achievement. The sciences and mathematics should be organized to show their interrelationships as well as their relationships with other disciplines. In order that teachers may be able to read educational and scientific literature, it is necessary to teach them how relationships are expressed in graphs and in equations, the purposes of constants, and the meaning of symbols.

SCIENCE AND THE PURPOSES OF GENERAL EDUCATION

The study of science should help prospective teachers understand the world about them. Concurrently, the instruction should help students realize that, in addition to solving practical problems, science can be a source of intellectual satisfaction. Content from the various fields of science can be selected for its value to teachers in their work with pupils and in their own personal lives outside of school. The instruction should supplement and build upon work previously undertaken. The biological and physical science courses should be organized with the specific needs of students in mind.

To provide a basis for those functional understandings that are a part of general education, the biological and physical science courses should be based upon appropriate laboratory and field experiences. Direct investigation through observation and experimentation should be exemplified in each course. The choice and adaptation of content to serve general education does not involve the lowering of standards but, on the contrary, will result in greater achievement than would be possible otherwise.

The Preparation of Elementary Teachers with Competence in Science

The task of becoming an elementary teacher involves the development of an understanding of the psychology of child behavior and knowledge of the growth and development of children. The prospective teacher should learn to direct the learning of children into those forms that will result in ready social adjustment and to prepare them for adolescence with its more complex challenges of both an intellectual and a social nature.

Such tasks involve an interpretation of the expectations and needs of society and of the procedures and methods of learning that will help the child develop as an individual personality as well as a constructive member of society. To promote the achievement of such competence in elementary teachers, the preparatory programs are most effectively based on experience with children.

Throughout professional preparation of teachers, content should play its proper role. With science, as with other subjects—reading, arithmetic, art, and social studies—the professional task is to determine how to use the content to promote the optimum growth of the child. Ideally, the study of how children learn and how to teach them and the study of science and its relation to child growth and understanding are an integrated part of the college curriculum. Provision should be made for panel or round-table discussions led by students in which their practical teaching problems can be analyzed. The analyses should be related to available knowledge on such questions as "What evidence of natural curiosity has been observed in the behavior of children?" "What field trips might be taken profitably in the vicinity of a certain school?"

The prospective elementary teacher should study the teaching of science in a room equipped with worktables and the kinds of teaching materials recommended for use in elementary schools. A substantial portion of the class time should be devoted to laboratory experiences in which activities suitable for children are tried. Subsequently, the class should gather together to demonstrate and report what they have learned and to consider how the experiences could be used effectively in the specific classrooms with which the students are concerned. Each student should speak in relation to his own

teaching situation, and thereby a broad view will be provided by the class, yet the proposed undertakings and their evaluation will be in practical terms. The laboratory should occasionally give specific attention to problems involving the construction, improvisation, and use of commonplace resources.

It is especially important that science courses for elementary teachers stress direct investigation in the laboratory and field because teachers learn to teach as they have been taught. For example, observation of metamorphosis as exemplified in the changes of insects is more effective than mere description. Many geological principles can be developed in relation to the local environment. Evidence of erosion is everywhere for students to investigate. In the northern United States, there is ample evidence of glaciation. In the Midwest and much of the South, the rocks are sedimentary and can be used to develop an understanding of the way such rocks are formed and how they are changed by weathering.

BREADTH OF OUTLOOK IN SCIENCE

Students of elementary education will not become specialists in science, but they will use science in their work with children and in the interpretation of their own daily experiences. No one can understand our culture, our institutions, or the prevailing philosophies without some knowledge of science and its origins. Elementary education, of necessity, includes more science than has been taught heretofore; elementary teachers must be prepared to teach it. But over and beyond what they teach, the teacher must have a significant grasp of the social impact of science. He must understand the scientific outlook and the breadth of scientific inquiry. He must be able to teach in terms of the general and the specific goals of science in the educational program.

Prospective teachers, themselves products of elementary schools, commonly have weak backgrounds in science, in comparison to other areas. Without sufficient education at the college level, a cycle of poorly prepared teachers, producing another generation weak in science, will be perpetuated. Leadership in public education can be provided by the colleges through adjusting requirements to the needs of the times. The prospective elementary-school teacher has

need for work in science beyond that recommended for the general education of all teachers.

Master's degree programs designed to prepare liberal-arts graduates for elemenetary-school teaching are likely to be crowded, yet no one should be certified for teaching without a course in science for children. Except for those students with a strong background in science, graduate work should include a course in science also. Suitable electives in science and the teaching of science should be provided for graduate students.

Professional Preparation of Secondary-School Science Teachers

The extent and kind of preservice professional courses or experiences needed by science teachers to enable them to teach science effectively has been a problem of teacher-training institutions for many years. That all science teachers must be competent in the subject-matter areas they teach is accepted by academicians and educators alike. For without this knowledge they simply cannot teach. The teacher must also know how learning takes place if he is to teach subject matter. Command of subject matter is only one of many competencies that a science teacher must possess for success in the classroom. Professional courses in education, when well organized and taught, can appreciably increase a teacher's understanding and effectiveness.

Reports of the American Council on Education,[1] the National Association of Biology Teachers,[2] the National Council of Independent Schools,[3] and other bodies agree that the kind of professional curriculum most useful to the beginning science teacher would include: (*a*) a study of basic aims of education in our society and the contribution that science can make to the realization of these aims; (*b*) a study of human growth and development and the learning

1. American Council on Education, Council on Cooperation in Teacher Education, *The Preparation of Secondary School Teachers.* Report of a conference held at the Princeton Inn, Princeton, New Jersey, September 28–29, 1956.

2. "Problems Related to the Teaching of Biology," *American Biology Teacher,* XVII (January, 1955), 42–43.

3. *Preparation of Teachers for Secondary Schools.* A report of the Committee on Teacher Training of the National Council of Independent Schools, May, 1958 (9 Milk St., Boston, Mass.).

process; (*c*) a study of the methods and techniques of teaching science and an understanding of professional duties and responsibilities of the science teacher; (*d*) an extensive, imaginative, and well-planned program of student teaching; and (*e*) activities designed to develop an understanding of the role of the science teacher in the guidance program.

ROLE OF THE SCHOOL IN SOCIETY

The prospective science teacher should have a knowledge of the history and traditions of the American school system and its role in a developing society. In addition, an understanding of the broad general aims of education and the contribution that science can make to the realization of these aims is essential for effective teaching. The science teacher must teach so as to demonstrate the function of science in our society and impart the method by which science has made contributions to society.

HUMAN GROWTH AND DEVELOPMENT

A knowledge of the growth and development of the adolescent, of the changes that occur in his interests, attitudes, and beliefs, and an understanding of the nature of the forces affecting adolescents are essential for competency in the science teacher. Such information aids the teacher in planning course content that provides for individual differences in students and in selecting methods and techniques of instruction that help students satisfy their emotional and biological needs.

NATURE OF THE LEARNING PROCESS

All science teachers need a thorough understanding of the basic principles that underlie good teaching. The following quotation lists under two headings certain principles that have been identified as essential factors in the joint process of learning and teaching.

THE LEARNER AND THE PROCESS OF LEARNING

1. Learning results from the active involvement of the learner.
2. Learning begins with the learner's present achievement.
3. Motivation increases the effectiveness of learning.
4. Learning occurs through various channels.

5. The meanings of words and other symbols are based on experience.
6. The total organism learns in responses to the total situation.
7. Learning varies with individual differences in need and ability.

THE TEACHER AND THE PROCESS OF TEACHING

1. Teaching and learning cannot be separated.
2. Effective teaching reflects the teacher's objectives.
3. Careful planning is essential to effective teaching.
4. Effective teaching is essentially good guidance.
5. Effective teaching is a deliberate, time-consuming task.[4]

Teachers with a clear understanding of the nature of the learning process should be able to act in accordance with these principles in motivating and helping the learner attain the goals of science instruction.

METHODS OF TEACHING SCIENCE

The course in the methods of teaching science should be closely related to the other professional courses. It should provide experiences in observing adolescents and in working with them. It must be based on an understanding of the purposes of education and of the materials taught. Moreover, there are clearly discernible areas that should be treated in such a course. Among these are: the impact of science and the scientific method on modern society; the place of science in the secondary-school curriculum; selection and organization of science content; methods and procedures by which the objectives of science-teaching may be achieved; selection and use of evaluation materials; and facilities and multisensory aids and resources. It should provide materials to promote the personal growth of the teacher and at the same time improve his technical skills.

The instructor assigned to teach this phase of the professional program should be well trained in the various science areas, and he should be an experienced secondary-school science teacher. Laboratory experiences are an essential part of the methods course, and opportunities should be provided the prospective science teacher to work with the type of laboratory materials and equipment usually found in the secondary school. This course should be taken prior to, or concurrently with, student teaching.

4. John S. Richardson, *Science Teaching in Secondary Schools.* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1957.

STUDENT TEACHING

One of the most important parts of the professional education program is student-teaching. Under the direction of a skilful and understanding supervisor, it brings into focus the concepts and principles explored in other professional courses. The student-teaching experience should extend throughout the day and should be continued for a full quarter or term. It should provide the student teacher with opportunity to observe and teach in his first and second fields of preparation.[5] The student teacher should assume full responsibility for classroom and laboratory activities during a major portion of his student-teaching experience.

GUIDANCE AND COUNSELING

The current shortage of scientists and engineers has increased the importance of educational and vocational guidance in the science classroom. A course in guidance should contribute to the teacher's awareness of the many career opportunities in science and engineering and should reveal sources of information regarding programs and requirements of colleges and universities and of available scholarships. Such a course should equip the science teacher to work with the school guidance director or counselor on common problems. The science teacher should understand the major areas of the guidance program and be able to use effectively the student information compiled in the counselor's office. Students with high-level ability in science and mathematics should be identified early, and provision should be made in the science program to make maximum use of their abilities and interests.

The professional preparation of secondary-school science teachers should be closely related to their academic preparation. The two aspects, content and method, are inseparable. Support seems to be developing for a distribution of college credit for the preparation of the science teacher in the following general pattern: general education, 30 per cent; professional education, 20 per cent; academic work in science and mathematics, 50 per cent. The interrelation of the pro-

5. *School and Community Laboratory Experiences in Teacher Education.* Washington: American Association of Teachers Colleges, 1948.

fessional and academic areas is promoted on many campuses through the services of an advisory committee representing both the professional and the academic areas.

The Science Teacher's Preparation in Science

Study in the sciences has two dimensions, breadth and depth. The successful science teacher needs both in his preparation, if he is to fulfil his function as an intellectual leader in the school and the school community.

NEED FOR BREADTH

The first argument for a breadth of preparation may be classified as scientific. The time is past that any scientist can limit his pursuit to a single discipline. Likewise, the science teacher needs more than a passing acquaintance with the various fields of science. He should have such command of the major areas of science that he can be intellectually secure in his own understanding of important advances in them. In turn, he can stimulate students and help them understand and interpret those subject fields. He must be able not only to help his students understand physics or biology but also must, himself, comprehend the field of biophysics, which incorporates physics and chemistry as well as biology and related sciences.

His second basis for breadth may be described as practical. The usual science teacher finds in his early teaching assignments, and often through his continuing service, that two or more subjects are assigned to him. While it is probable that new patterns of science instruction will evolve, a breadth of background will serve the science teacher in his teaching assignments for many years.

NEED FOR DEPTH

The first basic reason for depth is scientific in nature. The successful science teacher should experience continuous intellectual growth in a number of directions. Foremost among these is his growth in science. From this growth comes the satisfaction of his own intellectual drive and the understanding that ensues. He should come to understand science, with its unique purposes and procedures, as a function of society.

The second argument for depth is professional in nature and emanates from the need of the teacher to be able to stimulate students

intellectually. Much of this ability follows from the teacher's competence in dealing with recent developments in science. Through a depth of study in science, the science teacher is able to stimulate the students' interests and to guide their individual study. While we have long paid tribute to the concept of the individualization of our instruction in science, we have too frequently neglected the individual work that can be done with those students who show evidence of high intellectual ability. If the science teacher is to teach such students individually, he must have more than a general understanding of science.

COLLEGE PROGRAMS FOR SCIENCE TEACHERS

The usual college program for the preparation of science teachers makes at least a moderate provision for both breadth and depth of study. Over a period of years there has been an evolution of the programs offered by the college and university for science teachers. Initially such programs were limited very largely to majors within a single academic field, such as physics or zoölogy. Gradually, such majors have been modified and other courses included to provide a more adequate program.

PROVISIONS FOR BREADTH OF STUDY

Breadth of preparation of the science teacher is being provided in some measure in many institutions through the provisions for science in the general-education program. While this provision is not universal, there is growing recognition by institutions of higher education of the essential role of science in general education. While serious questions may be raised as to the adequacy of such provisions for assuring the development of an understanding of the role of science in general education, they should not be dismissed lightly in any consideration of the preparation of the science teacher.

A trend toward the development of a broader base for areas of major study and preparation for science-teaching is clear. In many institutions, the major field of concentration has been extended from preparation in a single subject to include two or more fields of science. It is not uncommon that a single major (often called a comprehensive major) includes course work from all fields of science that are relevant to the work of the science teacher. Such a program,

for example, provides a certain depth of study in the fields of physics, chemistry, and biological science and includes at least a modest amount of course work in such areas as geology and other aspects of earth science, conservation, astronomy, meteorology, physiology, health, and other related and applied fields.

The development of broadened major areas of study has presumably resulted from our increased understanding of the desired nature of the preparation of the science teacher and may also reflect changes in the organization of our secondary schools. The increase of the average size of our schools has resulted in fewer different teaching assignments for the science teacher. Consequently, the need to prepare in college to teach subjects entirely unrelated to science or mathematics seems to be disappearing. While the need will probably remain among the more sparsely populated areas for some time to come, it appears that it will become increasingly possible to give emphasis to the science background of the science teacher.

While no formula has yet been derived to determine the optimum amount of credit for courses in science, various institutions and professional groups have proposed that from one-third to one-half of the time available at the undergraduate level be devoted to course work in science. Unfortunately, the major concern has been only the quantity of hours; little or no attention has been given to the quality of instruction. In a few instances, provision for permanent certification within the state provides for continued study of science as a part of the Master's degree program.

PROVISIONS FOR DEPTH OF STUDY

In earlier programs for the preparation of science teachers, depth was presumably provided through a major area of study in a single field. This depth was accomplished through the election of the same courses in a field, such as physics or zoölogy, as those taken by students concerned with prespecialization in that field. To a considerable extent, the depth of study still depends upon such provisions. Such programs must be examined with care to determine whether depth of preparation for the purposes of science-teaching should be achieved in the same way as depth required as a basis for doing research in science. It cannot be assumed that depth of study

for the prospective science teacher and the prospective researcher is essentially the same.

Furthermore, it must be recognized that provisions for depth of study are not necessarily the same in the various fields. The person who plans to study physics in some depth will necessarily study a relatively greater amount of mathematics (in general, through calculus) than the person who studies in depth in biological science, where a knowledge of chemistry is essential. Study in depth in science necessitates also a study in breadth.

Research in the field of academic work for science teachers is much needed. While there is general agreement that their preparation involves a certain choice and organization of content, no criteria are available by which the choice can be made. As yet, both breadth and depth are conceived in empirical patterns.

Courses in Science for Secondary-School Science Teachers

In recent years there have been many attempts to diagnose the course-need problem in the preparation of science teachers. A number of institutions have devised various advanced science courses for teachers. The summer science institutes, especially those sponsored by the National Science Foundation, have provided an opportunity to explore the use of special courses for secondary-school science teachers. It is significant that a strongly urged qualification of a college or university to obtain one of these institutes was its willingness to organize one or more special courses for the teachers. This prerequisite has also obtained in the Academic Year Institutes.

The results of the experience in these Institutes is highly in favor of special courses at both the upper-undergraduate and the graduate levels. As a result of this exploration, it seems probable that several new types of courses may become available for science teachers in the future.

The course needs seem to fall into two classes: (*a*) courses for the experienced teacher returning to school and (*b*) courses for the prospective teacher who will need to obtain a breadth of training as well as depth in a particular field.

COURSES FOR THE EXPERIENCED TEACHER RETURNING TO SCHOOL

Different types of courses may be required for those teachers who were once moderately well prepared but who have not been able to keep up with the new developments in science, as opposed to those for teachers who were and still are poorly prepared.

Efforts to improve these teachers are limited by the fact that many of them do not have prerequisites for admission to advanced courses. For example, many teachers of chemistry do not have the prerequisites of physical chemistry or calculus to take the regularly offered advanced courses. Or teachers of physics and mathematics may have had mathematics years earlier and have made such little use of it that they are not now prepared to take advanced courses in physics and mathematics.

There seems to be little hope that many of the teachers, faced by the demands of diversified teaching schedules, will have time or will take time to acquire the prerequisites for graduate-level science courses. Similar restricting factors seem to be involved in the undergraduate programs for the preparation of science teachers. Because of the need for *breadth* of preparation, there is all too often not enough *depth* in any one area to make it possible to prepare the student to go directly into many of the generally offered "graduate" courses.

COURSES FOR THE PROSPECTIVE TEACHER OR FOR THE ORIGINALLY POORLY PREPARED TEACHER

For this group there seems to be no immediate need for special courses. Their first concern should be the completion of the approved regular undergraduate courses. Then they are ready for, and a number of them could profit by, one or more courses in "recent advances" in their field.

SPECIAL COURSES FOR SCIENCE TEACHERS

Two types of special courses have been designed by colleges and universities. Some institutions favor a course that may be described as an advanced general course with laboratory work. The topics may follow the sequence of topics usually found in the first-year college

course, but the treatment is richer and somewhat deeper. Such a course has the advantage of a review and distribution of topics, or breadth, but it may lack the depth or degree of concentration desired.

The "recent-advances" type of course has the advantage of providing depth in a limited number of topics. Such a course makes it possible for a teacher to feel more confident in his preparation. In addition, this type of advanced course is usually more acceptable to graduate schools for graduate credit than is the augmented review course.

SUGGESTED TOPICS FOR "RECENT-ADVANCES" COURSES

Examples of a series of topics for "recent-advances" courses are the following:

CHEMISTRY

1. *Particle Nature of Matter*
   a. Historical
   b. Evidence leading to concept of particles
   c. Evidence of elementary gases
   d. Evidence leading to proton, electron, and neutron
   e. Evidence leading to concept of structure of nucleus, proton, and atom

2. *Theory of Valence and Chemical Bond*
   a. Nature of covalent bond
   b. Nature of ionic bond
   c. Nature of hydrogen bond
   d. Nature of metallic bond
   e. Valence and oxidation number

3. *Fuels*
   a. Classical fuels
   b. Producing and processing gasoline
   c. Synthetic fuel processes
   d. New energy sources

4. *Atomic Energy*
   a. Historical
   b. Nuclear reactions (types, including fission and fusion)
   c. Use of Einstein equation to calculate energy equivalence
   d. Nuclear reactors
   e. Production and processing of fuel

5. *Tracers—Stable and Radioactive*
   a. Production
   b. Examples of uses

6. *Photochemical processes*
   a. Photosynthesis
   b. Laws of photochemistry
   c. Photocells

7. *Colloids*
   a. Preparation
   b. General properties
   c. Applications (foods, soils, plastics, rubber, dust, smoke, smog)

8. *High Polymers*
   a. Inorganic high polymers
   b. Organic high polymers
   c. Preparation
   d. Applications (proteins, carbohydrates, rubber, plastics, etc.)

9. *New Tools in Chemistry*
   a. Chromatography
   b. Nuclear magnetic resonance
   c. Tracers
   d. Mass spectroscopy
   e. Infrared

PHYSICS*

1. *Conservation and Transformation of Energy and Mass*
   a. Demonstrations of transformation
   b. Historical résumé
   c. Energy forms: mechanical, electrical, thermal, chemical, acoustical, optical, atomic, and nuclear
   d. Laws of planetary motion and gravitation

2. *Conservation of Momentum*
   a. Collisions
   b. Explosions
   c. Further examples including: the Compton Effect, *a* particles, detection of neutron collisions, and others
   d. Angular momentum

3. *Conservation of Charge*
   a. Static electricity
   b. Current electricity
   c. Electronic charge
   d. Electronics

* Contributed by Professor William R. Riley, Department of Physics, Ohio State University.

4. *Waves and Particles*
   a. Introduction
   b. Interference and diffraction phenomena: Light, electrons, X-rays, neutrons
   c. Polarization

5. *The Structure of the Atom*
   a. Pre-1900
   b. The changing picture, 1900 to the present
   c. Continuous, line emission and absorption spectra
   d. Instruments for studying atomic and nuclear structure

6. *The Molecular Structure of Matter*
   a. Introduction
   b. Kinetic theory
   c. Low temperature phenomena
   d. Electron microscopy

BIOLOGICAL SCIENCE†

1. *Principles of Organic Structure*
   a. Cells
   b. Protoplasm

2. *Principles of Function*
   a. Irritability
   b. Contractility
   c. Assimilation
   d. Respiration
   e. Secretion, excretion
   f. Utilization of energy
   g. Growth
   h. Reproduction

3. *The Principles of Environmental Limitations on Existence*
   a. Ecology

4. *Principles of Distribution of Life in Time*
   a. Past and present life
   b. Future life

The Influence of Noncollege Agencies on the Preparation of Science Teachers

CERTIFICATION AGENCIES

Certification should be aimed at the qualifications of competent teachers. The following is an analysis of a competent teacher:

† Contributed by Professor James G. Haub, Department of Zoölogy, Ohio State University.

> What is a competent teacher? He is one whose general liberal education has both breadth and depth. He knows his own areas of teaching well. He understands human growth and development and knows how learning takes place. He can appraise and help individuals. He is an expert in group processes. He possesses skill in methods of teaching, in stimulating careful thinking, in preserving and extending creativity of his students, skill in making them aware of the values they exhibit and in helping them re-examine those values from time to time.[6]

The above profile of a competent teacher provides a frame of reference for the examination of certification agencies and their influence upon preparation of science teachers. Certification is linked with requirements or standards for teacher preparation. When the common concepts of the broad aspects of an educated teacher have been agreed upon, these can be written into certification requirements.

Today, in most states, certification authority has been lodged in the state board of education or in the office of the chief state school officer. In many states, teacher certification began at the county level but has increasingly become a responsibility of state agencies.

Administratively, certification is a legal function; however, since certification is inextricably anchored to teaching as a profession and since certification sets minimum standards of teacher preparation, the granting of the certificate may properly be considered an insigne of professional status as well as one of legal sanction. Thus, as the chief state school officer takes on the role of professional leadership, the certification standards and procedures increasingly reflect the viewpoints and judgments of the profession. College graduation is recognized as the minimum preparation for admission to all major professions. As judged by this criterion, teaching is emerging as a profession.

Since 1946, twenty-one states have raised the standards of preparation for beginning elementary teachers to the degree level. Today, five years of college preparation are being recognized as the desirable minimum for all teachers, and it is recommended that standard certificates be based on six years of college preparation. Within the

6. Francis S. Rosecrance, "The Teacher and the Teaching Job—What Competencies Should Teachers Possess?" *Working Papers for Participants in the Second Bowling Green Conference*, p. 50. Washington: National Education Association, 1958.

framework of the four-, five-, or six-year standard for teacher preparation-certification, certain aspects of the program become significant. In certification patterns throughout the country, three major features are reflected: general preparation or liberal education; special preparation or specialization in the subjects to be taught; and professional preparation.

In a study covering thirty-eight states from which full information was available, it was reported that in 1957 the median certification requirement as set by the states for high-school teachers was 18 semester hours of professional education and that the average was less than 19 semester hours of such courses. For the academic field, the median and average requirements of the states, respectively, are as follows: English, 24 and 24+; modern languages, 20 and 22+; mathematics, 18 and 20−; science, 24 and 25+; physical science, 18 and 22; chemistry, 17 and 18; physics, 16 and 17−; biological sciences, 18 and 22−; biology, 18 and 18; general science, 18 and 22+; and social science, 24 and 26+. It will be noted that in every instance the median requirement in education (18) is equalled or exceeded by the median requirement in the academic field and subject, except in chemistry and physics, which are, of course, subjects within the broad field of physical science.[7]

It should be recognized that, in addition to the minimum requirements in these areas as set by certification authorities, each college approved for offering teacher preparation has the freedom to plan a program in excess of the minimum.

A recent case study reveals that thirty-seven states are functioning with councils or advisory committees on teacher education and certification appointed by the chief state school officer or the state board of education; that three additional states, although not maintaining a continuing advisory committee or council, do appoint representative committees to perform the functions of a council, if such action seems desirable.[8]

7. W. Earl Armstrong and T. M. Stinnett, *A Manual on Certification Requirements for School Personnel in the United States*. Washington: National Education Association, 1957.

8. Louise Combs, "State Provisions for Cooperative Planning of Teacher Certification Requirements," *Working Papers for Participants in the Second Bowling Green Conference*. Washington: National Education Association, 1958.

ACCREDITING AGENCIES

Accreditation is an integral part of the process of certification. There are three recognized types of accrediting agencies which have influence on the preparation of teachers. These are the state departments of education, the six regional accrediting associations, and the National Council of Accreditation of Teacher Education. In most states, teacher-education institutions must be accredited or approved by the state department of education if the credentials of their graduates are to be accepted toward meeting the requirements for teacher certification. Increasingly, the announcement of an accredited institution to the effect that its graduates have been selected and prepared according to an approved program is accepted as a basis for certification.

The Influence of Professional and Scientific Societies on the Preparation of Science Teachers

The shortage of science teachers has become so acute and its possible effects so alarming that many professional and scientific societies have become interested in the improvement of the quality of science-teaching and the recruitment of more science teachers into the profession.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

With financial support from the Carnegie Corporation, the American Association for the Advancement of Science launched its Science Teaching Improvement Program through the joint efforts of the Co-operative Committee on the Teaching of Science and Mathematics and the Academy Conference. The Co-operative Committee was organized in 1941 to work on those problems of science-teaching which are the common concern of educators, scientists, and mathematicians and which are better attacked by the co-operative action of many professional organizations than by the efforts of a single professional group working alone.

In a typical college science department, attention is usually concentrated on the preparation of students for graduate study in a science field, in professional schools such as medicine or engineering, or in

applied science work. The result is that students with interest and potential for high-school science-teaching are often shunted aside or inadvisedly discouraged. There is great need for more active encouragement of young people to prepare for teaching careers in the field of science. The AAAS is strongly urging the colleges to examine their undergraduate courses and major requirements with the view of improving the opportunities of future high-school teachers. College science departments are also being urged to work closely with departments of education and school officials to encourage revision of certification requirements so that greater stress will be placed on the subject-matter preparation of prospective science teachers.

A potential source of high-school science teachers includes the many persons who have had college training in science fields, such as engineering, premedical, liberal arts, and other programs, but who lack the required courses in education. Some of these students are known to have developed an interest in teaching too late in their college careers to take the usual sequence of education courses without unduly protracting their college programs. Others have waited several years after graduation before realizing that they would like to teach. To meet the needs of this type of prospective teacher, the AAAS is urging colleges to make special efforts to develop new programs.

THE NATIONAL SCIENCE TEACHERS ASSOCIATION

The National Science Teachers Association, with a program of services and activities directed toward improving science instruction in all fields and at all levels, exerts an appreciable influence on the education of the science teacher. It enrols student members, publishes *The Science Teacher* and the *Elementary School Bulletin*, issues *Packets of Teaching Aids for Science*, conducts regional meetings and a national convention, and carries on extensive committee operations. Its recently established Commission on Education in the Basic Sciences is charged to survey the present scene in science education and to develop programs and projects to help solve curriculum and teacher-education problems.

THE NATIONAL ASSOCIATION OF BIOLOGY TEACHERS

The National Association of Biology Teachers is the only national organization specifically designed to assist high-school biology teachers in the improvement of teaching. Its purposes are to facilitate the dissemination of biological knowledge, to encourage scientific thinking and utilization of the scientific method through the teaching of biology, and to make available to teachers recent findings of biological research in order to strengthen course content and presentation of laboratory materials. Its publication, *The American Biology Teacher*, is an important journal for science teachers. Many devices and ideas suggested by the association find expression in teacher-education programs for biology teachers.

THE NATIONAL ASSOCIATION FOR RESEARCH IN SCIENCE TEACHING

The National Association for Research in Science Teaching was organized for the purpose of promoting research in science education and disseminating the findings in such ways as to improve science education. Through its journal, *Science Education*, its College Level Research Committee, and its annual compilation of research in science teaching, the Association indirectly affects content and method in the preservice preparation of science teachers.

Conclusion

The evolution of the program to prepare better science teachers is reflected in the work of a variety of competent agencies. Two great needs have become increasingly evident from the activities of these agencies: (*a*) the development of instructional programs in science that serve effectively and uniquely the needs of prospective science teachers and (*b*) the development of a professional program understood and appreciated by prospective science teachers and related to the academic components of preparation for teaching. Satisfaction of these needs will require co-operative action between those whose major competence is in academic fields and those whose major competence is in the profession of education.

CHAPTER XV

The Professional Growth of the Science Teacher

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The professional growth of the science teacher has involved, during the last few decades, the acquisition, on the part of the teacher, of an ever increasing amount of knowledge and number of understandings. The rapid growth of science and technology has made the teacher's task of keeping abreast of developments a difficult one. The problems faced by science teachers in their day-to-day work have become increasingly complex. During the same period, the increase of knowledge relating to human behavior and the consequent gain in our understanding of the processes of teaching have given new dimensions to the problem of teacher growth.

Demands upon our intelligence, epitomized by our need for a scientifically literate citizenry and for an abundant supply of specialized personnel, have increased greatly during the past few decades. At the same time certain social factors have operated to reduce the strength of the science-teaching staff. The competition of science and industry with schools for educated personnel has tended to reduce the total number of teachers; it has operated to attract a disproportionate share of our ablest teachers into other occupations; and has tended to reduce the supply of science teachers. In the face of a greatly increasing enrolment in our schools, we must examine very critically the means not only of recruiting more science teachers but also of improving the performance of those who enter the field.

The Changing Function of the Science Teacher

In the Elementary School. The elementary-school teacher has unusual opportunities for guiding the learning of children. He is re-

sponsible for the teaching, not only of social studies, mathematics, language arts, music and rhythms, graphic arts, and physical education, but also of science. He is, therefore, in a position to co-ordinate all the learning experiences of children within the school day. He is able to consider the place of science in the total program for his pupils. As a science teacher, he must do his part in planning and administering a continuous, balanced, flexible program in science, a program firmly based on a sound philosophy and providing for the needs, interests, and abilities of the learners. In this role, the classroom teacher has the opportunity to provide each child with as good a foundation in science as is provided in any other area. Not only must this teacher assist in planning a program in science which has continuity from grade to grade but he must also insure its balance at each level. As a teacher of science he plans a variety of science experiences which will challenge each child in his group and especially challenge those children who are exceptionally talented in science. These experiences will build upon previous ones rather than repeating them. The science program will allow for activities of many kinds—discussion, reading, observing, listening, manipulating, working alone, and working with others. But whatever the program in science, the classroom teacher will try in every way to make content and activities point toward the realization of the purposes of science-teaching in the schools.

In some school systems, classroom teachers are assisted by consultants in elementary science. The consultant is a person who usually has a richer background in the content and the teaching of elementary science than has the classroom teacher. For this reason, the role of the consultant should be that of aiding the classroom teacher by suggesting possible content and experiences, providing materials, suggesting excursions, acting as a resource person, and giving guidance in developing the program in elementary science. The classroom teacher should be aware that his own activities should be related to and modified in the light of those of the science consultant. Through the development of understanding of the part that each plays in educating children, the teacher can greatly increase his effectiveness.

In the Secondary School. The science teacher in the secondary school is emerging from the position of a purveyor of information to

that of a social architect whose competence is in science. The needs of our society assign new functions to him; his professional growth must be governed by these changing functions.

How can a teacher develop in his students the understandings and abilities essential for life in the complex society of today? The teacher must direct the students' attention toward the aspects of science basic to living; he must motivate them to explore deeply one or more particular areas of science. He must organize instruction in such a manner that students can acquire important concepts by a scientific approach—that they may employ critical thinking to arrive at correct answers to questions and valid solutions of problems. Understandings, skills, and appreciations, with accompanying manipulative skills, can be acquired by means of observational and experimental techniques; appreciation for and commitments to science can be developed through creative expression of the concepts gained; and perspective can result from a recognition of the assumptions made and the questions that arise in connection with conclusions drawn.

The changing functions of science education require that the science teacher develop an enlarged conception of the role of content in the students' learning. Content must be regarded as both an important vehicle and a product of the experience in science. The science teacher must relate the science curriculum to the activities in science through which the students' special interests and abilities can find more adequate expression. Through his functions as a counselor, the science teacher must be able to help students assess their interests and competence, and, in some instances, to make at least tentative career choices. He will need to help students plan their work outside and even beyond the school—in the community, in summer learning opportunities, and even in college.

The development of competence for the performance of such changing functions is a heavy responsibility. This responsibility devolves primarily upon the science teacher. It must be shared by the school administration, by institutions that prepare teachers, and by the total educational community. A dynamic society must expect that its teachers will be able to perform the new tasks that fall to them.

Participation in Programs within the School

Opportunities for professional growth and responsibilities for service to his students and colleagues are often, as a teacher soon observes, two faces of the same coin. The science teacher can find an abundance of opportunities for growth within the professional activities of his school and the school system. Participation in committees, conferences, and workshops provides a means by which a teacher may grow in competence and stature in an on-the-job setting.

If we first consider those parts of a school program that contribute to the science teacher's general professional growth, several kinds of committee experiences can be noted. For example, meetings of the staff, organized as a committee of the whole, provide opportunities for the science teacher to listen to reports of studies made by others, to make such reports of studies in which he has participated, and to learn by participation in the discussions which arise in the course of the meetings. Also, participation in committee work involving staff evaluation of the total program of a school can be one of the most stimulating and rewarding experiences in a teacher's professional development. The evaluation instruments serve not only to check past performances but also to suggest future activities and to remind teachers of the goals to be achieved.

The science teacher, along with his colleagues, will be asked to serve on many smaller committees concerned with matters relating to the smooth operation of the school. While these duties are often tedious and time-consuming and sometimes seemingly unrelated to the teaching of science, they are still valuable for the insights they engender into problems of administration, curriculum, and public relations. For instance, a teacher serving on the school schedule or programming committee, may have undertaken, on the one hand, a chore involving petty clerical detail; on the other hand, he may have taken on a task providing opportunity to see the educational program of his school in its entirety.

If a school science department is of some size, departmental meetings can be used to advance professional growth in science-teaching. Sometimes such meetings are used to discuss and revise the science program. While such opportunities as the foregoing are not generally available in schools in which the science faculty is extremely small,

participation in programs involving students and their activities is often rewarding to the teacher. No school is too small for a science club, science fair, or science open house. The teacher-sponsor of such activities finds opportunity for professional development through participation in programs of this kind.

School systems organize various committees, conferences, and workshops to serve general school needs and also to help the individual teacher. The curriculum committee is one which serves both purposes equally well. Service on this committee gives the teacher a chance to help decide, on the basis of experience and study, what shall be taught and how the teaching shall be done; such service provides an opportunity for creative work and a chance to become acquainted with patterns and problems of science-teaching.

Many systems set up workshops to aid both the new and the experienced teacher. Such instructional workshops may be scheduled for orientation periods and planned specifically to help inexperienced teachers understand the nature of subject matter and acquire skill in methods of teaching. Other workshops may emphasize refresher sessions for the teacher who has been on the job several years. For either of these, some teachers may be called on to demonstrate superior techniques of instruction.

Occasionally, professional growth comes about through participation in programs which are associated with the school or school system but are not originated by the administration of either. An outstanding example of such an activity is the science teachers' club, more frequently found in metropolitan areas, one purpose of which is the exchange of ideas and information. Some of these clubs produce professional journals which are distributed on a nation-wide basis.

School programs which provide means for professional growth of teachers differ from place to place. Some will offer more and better opportunities than others. But the key to professional growth through such programs is teacher participation in them.

Formal Study in Colleges and Universities

Developing Science Teachers of High Quality. To provide appropriate experiences for boys and girls in the present scientific age, the high schools need science teachers of high quality. Science teachers

do not necessarily become well qualified simply by taking professional or academic courses in college or graduate school. The quality of teachers is related to their inherent potential and professional drive. Assuming that teachers possess these qualities, formal courses become the center of interest in programs designed for improvement in teaching skills.

Providing Appropriate Science Experiences for Youth. The major function of a science teacher is working with young people and providing for them those experiences which are effective in achieving the objectives of the school program.

Those who have taught or worked with high-school pupils are aware of the wide range of differences among them. Such differences are found in subject-matter background, in practical abilities and previous experiences, and in skills and interests in science and mathematics as well as in outdoor and other learning experiences. Children differ in attitudes toward the opposite sex, in how they identify with groups, in the nature and extent of participation in extracurriculum activities, and with respect to home life and parental relations. Hence, the teacher needs to understand something about youth and the world in which they live—how they are motivated and how they learn. Providing appropriate experiences in school sciences to serve the needs of young people becomes a real challenge for science teachers. To prepare them for their task, suitable professional courses and experiences are needed.

The Role of Educational Psychology. Frequently the beginning teacher or the prospective teacher is not ready or able to grasp the relation of psychological principles to teaching. After having taught a year or two, the typical teacher is better prepared to understand and use the principles learned in psychology courses. Educational psychology courses taken after a year or more of experience in teaching are more likely than those taken as a part of preservice training to have functional value for teachers of science.

Professional Science-Education Courses. After the science teacher has had a year or two of experience in the schools, he frequently is more concerned than before in the selection of experiences for science instruction and in their use. Professional courses in science education need to deal with practical problems of science-teaching. They need to help science teachers in such matters as locating and

using reference materials, presenting demonstrations, doing laboratory work, working with projects, using filmstrips and motion pictures, making and using slides, and guiding study.

One of the questions raised by returning teachers is how to teach effectively with the meager equipment and materials supplied them. The teacher must frequently learn to work with, improvise, and repair apparatus and devices for use in high-school classes rather than to depend upon commercially produced apparatus such as is used in college courses.

Attention to Curriculum and Evaluation. The graduate program for science teachers should be designed to help them develop perspective with reference to the science curriculum and proficiency in evaluating the results of science-teaching. Because of the nature of his own schooling, the beginning science teacher generally looks upon the science curriculum of the school as simply an aggregation of separate courses. In his graduate professional study, the mature student will understand that formal courses are the means of integrating experience in science with his experiences in other fields of study and with normal types of experience in life outside of school. The development of such understanding involves the comprehension of science content as functional in the total learning process rather than as subject matter to be memorized.

Another major need of the science teacher is that of an enlarged conception of the function of evaluation in the teaching of science. The usual approach is that of testing for subject-matter retention. Without minimizing the role of content in learning, it is essential that teachers learn that evaluation must be based upon desirable outcomes of science-teaching. Very few teachers would argue that the development of ability to think critically is unimportant. Yet, it is the unusual teacher who makes an attempt to evaluate the progress of the student in the attainment of this objective. Evaluation must be related to the teacher's objectives if it is to have meaning for the teaching process. Every accepted objective of science-teaching must be represented in some way in the evaluation of student growth in science.

Knowing about and Using Resources. Many returning science teachers find that they lack ability and skills needed to make use of available science resources. If one of the purposes of science-teaching

at the high-school level is to learn to apply science in everyday living, many resources outside of the textbook should be utilized. A teacher of limited experience may be unaware of the amount of free and low-cost materials available for use in science classes. Such materials include publications of government and professional organizations and the publications, audio-visual aids, and other materials provided by industrial and commercial companies. In addition to knowing the range of resources, teachers need guidance regarding the collection, organization, and use of such materials.

Continuing Academic Work at the Graduate Level. Since high-school science teachers are often poorly prepared in content, science courses should be included in graduate programs designed for them. The courses should deepen the teacher's understanding in a particular area or broaden his understanding of several related areas.

New advances in science also suggest a need for courses in such subjects as atomic energy, electronics, space flight, and biological developments in modern agriculture. In general, work in appropriate courses is preferable to individual reading as a means of acquiring additional preparation.

Reading and Professional Growth

Science teachers face the difficult task of keeping up with recent developments both in scientific knowledge and in professional practice. This has always been true, but rapid growth of scientific knowledge and international competition in science and technology have emphasized the need for science teachers possessing a high degree of subject-matter competence. Owing to personal and financial reasons, many experienced teachers have not been able to continue taking additional professional work in colleges and universities.

Some teachers maintain a reasonably high level of competence through following a carefully planned program of reading. This reading includes both current periodical literature and new books related to their chosen fields. For convenience of discussion, types of useful reading materials for science teachers may be divided into three main categories: (*a*) professional, (*b*) scientific, and (*c*) general.

CURRENT PROFESSIONAL LITERATURE

Professional Journals and Magazines. A variety of professional journals and magazines emphasize the teaching of science, while others are more concerned with recent discoveries in science. Those in the second group, however, often publish useful articles on methods of teaching specific concepts and principles. Science teachers should read regularly several of the following professional and scientific magazines.

The American Biology Teacher
American Journal of Physics
Journal of Chemical Education
School Science and Mathematics
Metropolitan Detroit Science Review
The Science Teacher
Nature Magazine
Physics Today
Science Education

Professional Books. Each year several professional books relating to science-teaching are published. The book-review sections in most professional periodicals generally announce and often review such publications. By using such sources, the science teacher may select professional books to promote his own growth.

CURRENT SCIENTIFIC LITERATURE

Current Periodical Literature. Knowledge and understanding of recent scientific discoveries are urgently needed by most science teachers. The growth of science is so rapid that textbooks cannot possibly be revised as often as would be necessary to keep them up to date. Thus, the science teacher is obliged to supplement them with other sources of information. Articles in current periodicals provide at least a part of the answer. The science teacher must choose carefully if he is to obtain optimum value from his reading in magazines, journals, and newspapers. Many reports of scientific developments are written especially for the general reader, with the technical aspects kept to a minimum. Science teachers have found the following periodicals to be a constant and reliable source of new information and ideas:

Scientific American
Science
Physics Today
Weatherwise
Nature Magazine
Audubon Magazine

American Journal of Physics
Journal of Chemical Education
Review of Modern Physics
Popular Science Monthly
Science Digest
Outdoors Illustrated
Natural History
Junior Natural History
Science News Letter

Science teachers should be acquainted with the periodicals available for high-school science students. These publications should be an important part of the materials for science instruction. Such periodicals include the following:

Tomorrow's Scientists
Chemistry
Science World
Current Science and Aviation

Many newspapers carry short articles concerning science, and a few have regular science columns each week. Dependable columns are found in the *New York Times* and in the *Christian Science Monitor.*

Sources of Recent Science Books. Current books describing more recent developments in science are generally listed in the book reviews and annotated bibliographies of such magazines as the *Scientific American*, *Science*, and *Science News Letter.* Science teachers may have their names placed on mailing lists of publishing companies. The companies send regular announcements of new books in the fields of the teacher's interests. In selecting books in science, care must be taken that the books selected are not beyond the teacher's comprehension.

GENERAL READING FOR PROFESSIONAL GROWTH

Kinds and Sources of Professional Literature. Another important area of literature for the well-rounded science teacher includes those books and articles which deal with the history and philosophy of science and with social implications of scientific discovery. In the past, many such books have been expensive, but recently a number of them have been printed in inexpensive paper-backed editions. Lists of titles for this area of reading may be found in both published bibliographies and in current periodicals. General reading of this nature will contribute greatly to the professional growth and competence of the science teacher.

The Science Teacher in Relation to the Federal Government

Traditionally, education has been a function of the state. Through the decades, however, the federal government has assumed certain responsibilities and engaged in certain educational activities. Particular examples of these are found in the area of vocational education. The government appears to have initiated action in time of peril or of great need for a particular type of education.

In recent years, the rapid developments in science and engineering have become the concern of responsible agencies of the government and have been intensified by the decline of the number of available teachers, by the obvious need for more and better prepared science teachers, and by the knowledge of the tide of youth about to enter the secondary schools.

The federal government has attempted through many departments and agencies to give aid to the teaching of science. Among the most influential efforts, particularly with reference to the number of teachers affected, have been those of the National Science Foundation, the Oak Ridge Institute of Nuclear Studies, the Public Health Service, the United States Office of Education, and the President's Committee for Scientists and Engineers.

The National Science Foundation devoted its efforts initially to scientific and educational programs that promised to increase the scientific research productivity of our nation. It soon became evident that attention should be given to educational programs in science in the secondary schools as well as to those in colleges and graduate schools. Also, the preparation of science teachers became a matter of serious concern. At least four major programs have been developed by the National Science Foundation. These include the Academic Year Institutes, presently thirty-two in number, and more than three hundred summer institutes. Each of these institutes provides for about fifty teachers of science and mathematics. In a number of metropolitan communities, in-service institutes are provided for employed teachers. In addition, fellowships for science and mathematics teachers have been made available by the Foundation to enable teachers to study in institutions of their choice. Also, the National Science Foundation has promoted the up-grading of the science

teachers through lecture programs in the schools and through institutes in radiation biology provided in co-operation with the Atomic Energy Commission.

The Oak Ridge Institute of Nuclear Studies has developed institutes in radiochemistry and radiobiology for those persons who will teach these subjects in colleges and universities. Indirectly, this effort has been of great value to science teachers. The Oak Ridge Institute has developed traveling exhibits in the field of atomic energy. These exhibits have been made available to science teachers and their schools. Also, several traveling science teachers have been supported for a year to put on demonstration-lecture programs in schools, and a summer program for the initial preparation of these teachers has been provided.

The Public Health Service, working through the National Cancer Institute and through other agencies of the National Institute of Health, has provided leadership in the improvement of science-teaching. For a period of several years, the National Cancer Institute has given support to the science-teacher achievement-recognition program for which the National Science Teachers Association has provided leadership.

Through all these efforts there has been a measurable contribution to the academic preparation of the teachers. Efforts have been made to bring the teachers up to date in their knowledge of science and in certain of its applications. At the same time there has been a noticeable improvement in the professional competence of the teacher as well as an improvement of the teacher's status.

The United States Office of Education, through its specialists in science, has made an outstanding contribution through the provision of information about the status of science-teaching and through a factual report of need for science teachers. Also, these specialists have helped improve science-teaching through consultation with appropriate bodies. The National Defense Education Act provides several means by which the Office of Education can affect the teaching of science, both directly and indirectly. The President's Committee for Scientists and Engineers has served to assess the need for personnel and to estimate our educational potential. It brought together and published information concerning community programs

and served to stimulate considerable effort for the improvement of programs designed for science and mathematics teachers.

The role of the federal government in educational activities will perhaps never be established with finality. In a dynamic society, no final determination is to be expected. That federal funds have helped provide states and communities with certain services which will improve the quality of science-teaching is beyond doubt. The permanent increment from this support may well be found in the colleges and universities that prepare our science teachers. The lack of concern for preparation of science teachers found in many of these institutions has been brought into a sharp contrast with the needs of other institutions for teachers. At no previous time in history has there been such a widespread joining of efforts of the professional educator and the professor of science to improve the preparation of the science teacher. The purpose of the federal government will be in large measure fulfilled when such co-operation becomes permanent.

Activities of Industrial, Philanthropic, and Other Agencies

The recent awakening of public interest in science and education has led to the organization of many community-action programs designed to stimulate improvement in science and mathematics programs in the schools. Most of these programs have as their primary aim the location and development of prospective scientists and engineers; a few profess purposes which are broader and more fundamental. Some programs are based in the schools of the community; a very few are supported by individual corporations; others are based in volunteer organizations. A very few are well-financed; most are currently struggling for funds with which to work.

Present programs tend to mix concern for better instruction in science and mathematics with concern for educational provision for abler youth and for "toughening" the secondary-school curriculum. Very infrequently do these programs concern themselves with improvement of the general-education effectiveness of precollegiate science and mathematics courses or with educational provision for the less-able segment of the public school population.

Activities encouraged by the various programs encompass virtual-

ly all those urged by the statements of leading public figures: industrial tours; summer employment for teachers; science fairs; television and radio programs; support of science-teacher trips to conferences and conventions; loans and scholarships for prospective scientists, engineers, and mathematicians; conferences of teachers and others on the improvement of education in science and mathematics; and the like. However, most community programs in operation at the present time suffer from their failure to recognize and to gain access to the main-springs of school curriculum reform.

Four efforts which have broad community support and which show promise of escaping this defect are those of the Industry-Schools Committee on Science and Mathematics Education of Indianapolis, the International Paper Company Foundation, the Thomas Alva Edison Foundation, and the Frontiers of Science Foundation of Oklahoma, Inc.

Since 1946, the Thomas Alva Edison Foundation has been working actively at projects designed to stimulate research in education, to improve science education in the United States, and to encourage young people to select careers in science and engineering. The Foundation supports the National Science Youth Day, the National Mass Media Awards in films, radio, and television, the publication of children's books and so-called "comic" books, annual nation-wide science-education institutes, and, more recently, conferences on co-operative education and a state-wide project co-ordinating science education with industry. The Foundation maintains an extensive publications program as well.

The International Paper Company Foundation has recently financed an educational survey in six states by a major college of education and, on the basis of that survey, has instituted educational-improvement programs in the southern communities in which its plants are located. The Foundation's activities have been expanded on the basis of another survey to include its plant communities in three northern states.

In the Indianapolis effort, ten science educators and seven representatives of local industry and business have joined in a committee whose chairman is the assistant superintendent of the Indianapolis Public Schools. The sponsors are the Indianapolis Board of School Commissioners and the Indianapolis Chamber of Commerce. The

Committee's primary purpose is to help science teachers. Major activities have included urging boards of education of area school districts to increase their financial provisions for instruction in science and mathematics; promoting industrial tours for secondary-school science students; modifying the annual Indianapolis Business-Education Day for special stimulation of science and mathematics teachers; developing, through interested universities, refresher courses for science and mathematics teachers; and assisting in the financial support of the state Science Talent Search.

The Frontiers of Science Foundation of Oklahoma, Inc., is a nonprofit corporation listing some one hundred fifty members drawn from industrial, educational, and professional leadership in the state. Its effort is state-wide, and it has been financed through contributions by the members of the Foundation. Its purposes are broad, including improvement of the general-education aspects of science and mathematics; location and development of abler youth; attraction of scientific and engineering laboratories to Oklahoma; the strengthening of personnel and facilities for research and development in science, mathematics, and education; and the development of better public understanding of modern science and its impacts on society.

The Foundation has organized several large programs that have treated modern technology, some of which have been attended by hundreds of thousands of individuals. It has sponsored state-wide conferences on the improvement of curriculum in science and mathematics, resulting in new curriculum publications; made research grants to scientists in Oklahoma's smaller colleges and universities; provided for development grants to public schools for the use of television in teaching science and mathematics; published guidance pamphlets for secondary-school youth; contributed to the support of elementary training on computers for mathematics teachers, a traveling science lecture series for high schools, and a television program in modern mathematics for high-school teachers; and financed the distribution of educational materials and scientific information among all secondary-school teachers of science and mathematics in Oklahoma.

In both the Indianapolis and the Oklahoma programs, the early design for the selection of groups insured involvement of school leaders, professional people, and businessmen. Through this involve-

ment, both programs have found it possible to reach well into the mechanisms of program change within the schools and to bring about significant improvement of the climate for education in science and mathematics and important shifts in the choice-patterns of the members of the school-age population.

Special Problems of the Converted Science Teacher

The phenomenon of converted[1] science teachers is not new. Their existence has been reported repeatedly in studies of teaching loads and combinations of subjects taught. In small schools, especially, teachers have for years been converted from one teaching area to another. Today, however, the converted science teacher merits special consideration. World tensions and crises have served to emphasize the urgent need for leadership in science and technology at a time when our nation is faced with a critical shortage of competent scientific manpower.

Even more serious is the shortage of qualified secondary-school science teachers whose role in encouraging the needed manpower is all-important. School enrolments keep increasing steadily while the supply of college graduates prepared to teach science remains consistently inadequate. Consequently, it seems inevitable that, unless remedial steps are taken, the number of converted science teachers will increase, possibly to major proportions in the future.

The help needed by converted science teachers differs from that needed by those trained to teach science. Their immediate needs are many. They need to learn content and to identify and manipulate science equipment. They have difficulty in selecting and organizing science materials, demonstrations, and projects. They are unfamiliar with the various techniques involved in teaching science and, consequently, have trouble in planning their classwork.

These teachers are hesitant to ask for advice or assistance. In the small schools where there is no department head, the other science teachers are often too busy to give more than limited help. In the

1. For want of a better word, the term "converted" is used to designate those persons, teaching science either full time or part time, who have had little or no background in science and whose collegiate specialization has been in fields other than science.

larger schools there is a department head who may be able to assist new teachers, but only at scheduled times instead of when he is needed. Furthermore, many converted science teachers are unwilling to ask for help, lest it might imply incompetence. Thus, it is quite understandable why these teachers rate low in job satisfaction and attitude toward teaching science.

There are several lines of action which would improve the teaching effectiveness of the converted teachers. First, they should be encouraged to take college courses which will both extend their knowledge of the subject and aid them in structuring classroom experiences.

Second, they should take courses on the teaching of science, which will help them select and use appropriate materials for classwork, plan instruction which involves varied teaching techniques, and introduce them to the many organizations, journals, and publications of value to such teachers and their students.

Third, the converted science teacher should be provided with every opportunity to participate in in-service education activities of proven effectiveness. They should be encouraged to visit science classes taught by competent science teachers. Special committees, conferences, and workshops could be organized in which they can work and plan with experienced teachers. A professional and reference library should be provided.

Finally, in order to meet the immediate needs of the converted science teacher, an experienced science teacher should be made available to advise and help him at any time. Such an experienced teacher should be selected for his ability to communicate sympathetically and should be properly remunerated for this added responsibility. The experienced teacher could meet regularly, at least once a week, with the beginner and help him with lesson plans, techniques of teaching and testing, selection of materials, and choice of materials to be read to expand his knowledge. Such a system of pairing would be beneficial to both teachers. The converted science teacher would obtain the help he needs from an experienced fellow teacher rather than from an administrative person whom he might be reluctant to approach. The experienced teacher would be publicly recognized and rewarded for his knowledge and skills.

Conclusion

A profession is characterized by the nature and values of the services its members render to society. In a society characterized by its achievement in science and by a growing body of professional information, the obligation of the teacher of science to acquire professional status is clear. The hallmark of a profession is the recognized competence of its membership. As science-teaching advances to professional status, the need for continuing competence becomes more critical. As individuals and as professional groups, science teachers are finding ways to grow, both professionally and academically, through activities sponsored by schools, colleges, and universities, as well as by various professional and scientific societies.

The concern of society for maintaining and increasing the competence of the science teacher is made evident in a variety of ways. Various agencies have attempted by different means to improve the quality of science-teaching in communities of all sizes. The spectrum of concern has included that of local organization of engineers and industrialists at one end and that of the national organizations in the sciences and the professions at the other; that of the local board of education at one end and that of the federal government at the other. Many such bodies in our society have attempted to increase the teacher's effectiveness by those methods which were within their understanding and with the resources that were available to them. Teachers of science education are in a unique position in this great effort. Within this segment of the teaching profession are the persons possessing both academic and professional competence. Because they possess these competences, it is their responsibility to provide the leadership that will insure that science-teaching realizes, to the extent possible, the purposes of science education.

CHAPTER XVI

Needed Research in Science Education

FLETCHER G. WATSON and WILLIAM W. COOLEY

Confident theory and practical action in education, as in science, must be based upon the results of research. However, now that the spotlight of public concern has been turned abruptly upon science-teaching in the schools, we find that proven research in this area is not sufficient to guide us in determining what changes would be profitable for improving the teaching of science. Some advances have been made, but only on a narrow front.

In order to determine what research *is* needed, it is first necessary to identify the areas in which current and previous research have tended to concentrate. Having this "inventory," it will then be possible to see what territories need increased exploration. A picture of current research in science education can best be obtained from the annual reviews of research which have been published during the last few years.[1] An analysis of these reviews indicates that most of the studies reported are one of three types:

Status Studies. These include surveys of current practices in certain states in teacher education and in teaching particular subjects; teacher supply and demand surveys; polls of the present vocational plans of high-school students; and the examination of science textbooks for content, and to determine trends relating to the content and the teaching of science. Such status studies describe the present state of affairs; when compared with earlier reports, they reveal changes that have occurred in the past and may suggest changes yet to come.

Methods Studies. Investigations of methods, for the most part, involve comparisons between gross teaching procedures (e.g., unit *vs.*

1. E. S. Obourn, *Analysis of Research in the Teaching of Science.* U.S. Department of Health, Education, and Welfare, Bulletin 1958, No. 7. Washington: Government Printing Office, 1958. See also the annual reviews of research usually appearing in December issues of *Science Education.*

traditional approach; inductive *vs.* deductive-descriptive; laboratory *vs.* demonstration; and films *vs.* teacher-traditional) *and generally employ gross criterion measures* (usually a pre- and post-test model using achievement measures).

Opinion Studies. To provide data for these studies, prominent educators or scientists are asked to make judgments regarding the relative importance of certain scientific principles, about which courses prospective science teachers should take, and about what the content of high-school physics courses should be.

These studies describing present status, gross procedures, or opinion are often useful in restricted contexts. But what we need for wiser decisions are dynamical descriptions as to how and why the status or achievements or opinions changed. The existing studies may be used to suggest where and how to search for the dynamics of change, but they provide an insufficient basis for decision-making not only because they are limited in nature but also because of certain weaknesses in the research. In much research, neither the questions asked nor the data collected have been such that permit broad application of the findings. Also, there is often an unfortunate lack of clarity in the reports, which prevents them from being replicated. Because teachers sense that a large number of variables influence learning, studies of a small number of pupils in a few classrooms taught for a few weeks or months by ill-defined methods and appraised by unspecified means for unclear purposes are hardly convincing to them. Furthermore, the treatment of the data has often been incomplete or invalid. These reports simply do not carry the conviction which evokes belief and leads to modified actions by the reader. In view of these and other defects, it is not surprising that most of the research fails to influence the thought and behavior of teachers. Unfortunately, the competent, valid research is disregarded along with the incompetent and the invalid.

It is easy enough to offer negative criticism, but it is quite another problem to describe positive lines of action. What new approaches are needed if a sound body of knowledge about science education is to be developed? In science education, as in other fields of inquiry, the profitable lines of attack are not likely to deal with the most obvious phenomena. The subtle and fundamental features of science education are what give meaning to the symptoms observed and

make prediction possible. To us, the principle task of educational research is the development of reliable predictive systems based upon laws and principles applicable to the fundamental problem of maximizing learning in the schools. But the development of "laws and principles" which describe such complex processes as the teaching and learning of science will require research far more basic and imaginative than most previous and current efforts.

Areas of Needed Research

It is a rather difficult task to divide into particular problem areas the teaching and learning of science, with all the complex emotional interactions between the pupil and the teacher, the vast domain of science to be considered, and the extreme variety of cultural and physical environments within which teaching occurs. No one individual can hope to solve the "whole problem." Instead, we must select certain significant characteristics of the whole and deal with them. Then *slowly*, more general principles may evolve from the specifics, and we may eventually arrive at a science of science education.

Specific areas which require more research are considered in this chapter in relation to (*a*) the learning process, (*b*) the learner, and (*c*) the teacher. Of course one aspect cannot be considered to be independent of the others, but that would be true of any classification scheme which might be proposed.

THE LEARNING PROCESS

The unique purpose of schools is to create within pupils certain types of cognitive learning and standards of critical judgment which are not commonly acquired through day-to-day social contacts in the community and home. While we do not deny that the school has a responsibility for the socialization of the child, this function is not unique to the school. Socialization is influenced by a myriad of experiences the child has throughout the day in school, after school, in the home, and in the community. The school, however, is the only social organization established primarily to impart the skills, attitudes. and understandings in the major fields of knowledge. We must, then, be centrally concerned with what the child learns, the conditions under which different individuals achieve this learning most rapidly,

and the evidence each child gives of having achieved the objectives of science education.

Cognitive Learning in Science. The readiness of each individual pupil and the structure of the subject come together in the process we call "learning." Teaching is then the procedure by which we attempt to expedite or catalyze this learning. Without serious and continual study of the complex learning processes required *in the sciences,* we have no adequate basis on which to define, investigate, or appraise science-teaching methods.

Presumably for help in understanding the learning processes we should rely upon studies made by psychologists. However, this is not currently possible. When the Advisory Board on Education of the National Academy of Sciences considered means to improve science education, ". . . questions were raised about the status of basic research on fundamental processes in education. Examination indicated that relatively little direct attention was being given to these problems by experimental psychologists. The complexities of the problems make extremely difficult the acquisition of meaningful data out of which fundamental concepts and theories can be derived. However, it is of vital importance that sound principles be available for guidance as our educational institutions continue their rapid expansion programs and strive to improve teaching and the curriculum."[2] Furthermore, a group of psychologists meeting under the auspices of this same Board reported that "there was general agreement that research on intellectual development, and especially on problems fundamental to the understanding of intellectual learning in the schools, had been seriously neglected."[3] In a second report on the contacts between psychology and education, another group observed that, from 1890 to 1920, those who did research in these areas also assisted importantly in the shaping of educational developments, theories, and methods. In recent years this close liaison has been largely lost, especially between practical educators and research psychologists."[4]

2. *Psychological Research in Education,* p. ii. Washington: National Research Council, National Academy of Sciences, 1958.

3. *Ibid.,* p. 1.

4. *A Proposed Organization for Research in Education,* p. 4. Washington: National Research Council, National Academy of Sciences, 1958.

A large literature of potential relevance has been developed, at least part of which has been summarized in the volumes by Vinacke[5] and by Russell.[6] Also, Piaget in Geneva has persisted in his inquiries into how children learn the things we teach in school. Without arguing about the details of his conclusions, many leads to further inquiry stem from his investigation. For example, his large *Genetic Ontology*, soon to be available in English, and another volume written in collaboration with Inhelder[7] are particularly suggestive.

The responses of adolescents have been so conditioned by earlier schooling and affected by their general physiological and mental development that studies of their thinking processes are likely to be complicated ones. With Piaget and others, we may agree that studies will be most profitable if they begin with quite young children whose framework of ideas and responses is relatively uncomplicated. Young children are so naïve, open, and revealing in their reactions that inferences about how they learn are likely to be valid.

Although it cannot be assumed that older children learn in exactly the same manner or with the same emphasis, suggestions from work with younger children should help in clarifying what to investigate and how to proceed with older children. In particular, attention could be focused initially upon the conceptual processes by which young children form categories, and whether these deal with static or dynamic attributes of the phenomena. Grouping into categories is itself one aspect of concept formation. Bruner and others[8] have published a volume which has major research implications for this problem. They are concerned with the conditions related to "concept attainment," i.e., acquiring the ability to distinguish between events and objects which should or should not belong in a given category. The history of science reveals the importance of dynamic descriptive systems as bases for predictions and judgments. If we wish children to develop skills in making applications and in judging the desirabil-

5. William E. Vinacke, *The Psychology of Thinking.* New York: McGraw-Hill Book Co., 1952.

6. David H. Russell, *Children's Thinking.* Boston: Ginn & Co., 1956.

7. Jean Piaget and Bärbel Inhelder, *The Growth of Logical Thinking from Childhood to Adolescence.* (Translation by Parsons and Milgram.) New York: Basic Books, 1958.

8. J. S. Bruner, J. Goodnow and G. A. Austin, *The Study of Thinking.* New York: John Wiley & Sons, Inc., 1956.

ity of anticipated reactions, the sciences would seem to offer an ideal area of experimentation. *However*, we have little clear evidence as to how and when the developing child, provided with selected experiences, can form dynamic classifications. Our intentions must be consistent with what the child can do; and we do not know much about the child.

Clearly, initial studies must deal with the learning and reactions of individual children. Piaget's work is frustrating in that he provides so little information about the individual child. We need to take into account their home and school backgrounds, general intellectual ability, sex, age, and other less obvious attributes.

The new experiences provided must be described in detail and should be presented according to set protocols, or procedures, to insure that the exposures of different children will be similar, if not identical. Likewise, the evaluation or test conditions must be identical. More important, they must be planned to reveal the wide range of learnings and reactions that may result from the addition of a particular experience to that previously organized by the child.

Since children and learning are so complex, introductory studies should not attempt to be normative. Instead, detailed study of a few children might provide promising hypotheses about how children learn specific aspects of science. These hypotheses can then be tested in experiments dealing with larger groups of children.

Reports of such exploratory experiments must be made in detail so that others may know just what was done to whom, and in what manner, with a clarity that invites repetition of the experiment. At present we are hampered by lack of a vocabulary like those in the sciences (filter, centrifuge, weight, titrate, balance, section) to describe tersely the operations carried out. Perhaps eventually such a vocabulary with specific unambiguous operational meanings will be developed in education.

Certainly cognitive learning in science is a challenging area for investigation and the one area most basically related to the problems confronting those who would improve science teaching. Chapter iii of this volume reports on a number of studies concerned with aspects of cognition and attitudes in science education. The nature of the difficulties of research in this field are pointed up by the difficulties that arise in defining and studying such general aspects as "critical

thinking," and "scientific attitude and methods." The analyses of psychologists suggest that more stable and useful results might be obtained through detailed studies of particular learning tasks, such as those involved with specific scientific principles. Regarding an approach to research in these areas, psychologists observed that "a cardinal need was a breaking down of these tasks or subject matters so that they become more understandable in a research sense."[9]

While we may hope that the task of inquiring into the learning process in science will not continue to be left to the science educator, we foresee that those concerned with teacher-training and curriculum revision must become more informed about psychology and its implications for the classroom. The question of who is to do the needed research will be discussed at the close of this chapter.

Design of Instructional Materials. In their efforts to improve the planning and operation of science courses, most teachers are severely hampered by the lack of an adequate rationale of teaching and of learning. Such a rationale should contribute to the production of instructional plans as clear and operational as a musical score. Such planning requires a knowledge of how children learn science concepts, but we cannot wait until "all" is known about learning science before taking steps to further progress in this important area. Certainly what is now known can be profitably incorporated into the design of planning schemes. Teachers need some framework which will aid them in making explicit in advance the objectives of each day's classroom activities, the nature of the experiences to be used to evoke the desired learning, and the behavior reactions sought from pupils as overt evidence that learning has occurred.

There already exist several suggestions as to the possible nature of such schemes or formats. One phase of research on this problem might be concerned with surveying existing psychological knowledge to see whether such formats are consistent with what is known about learning. A second problem to investigate is whether or not teachers can design such plans with validity and use them effectively. Perhaps another research approach would be to test the ability of other teachers to read the script and visualize the pupil behaviors. If formats can be found which are psychologically sound and do, in fact, facilitate the planning of lessons, and if the resulting plans are

9. *Psychological Research in Education, op. cit.*, p. 8.

intelligible to science teachers, such formats will certainly contribute to the improvement of the teaching of science. Since we can write poetry, music, and modern dance in symbols, surely we should be able to write at least a rudimentary description of teaching.

Evaluation of learning outcomes. A third area of the learning process in which serious study is needed is that of evaluation. To us evaluation means far more than testing. The evidences of effective learning must appear in changed behaviors of the learners. While this behavior includes making correct responses on tests, it also includes the day-to-day actions of the pupils in class while their attitudes and motivations are under observation.

Unfortunately, the objectives of teaching science are often stated in grandiose terms; rarely are they in terms of specific observable learned behavior. Without such specificity, we lack criteria by which we can determine whether our instruction made the most of the possibilities afforded by the material. That many teachers are weak or vague in their evaluation is particularly unfortunate, since so much importance is placed upon grades. Also, it is obvious that effective evaluation would feed back to the teacher much useful information by which his instruction might be modified and improved.

Even in the restricted area of test construction, there is a paucity of competent experts. Most of those to whom we turn for advice are generalists in their knowledge and are not intimately familiar with science and its teaching. Of the others who have such special skills and knowledge, many are in the employment of testing services, which limits their freedom to criticize. For improvement in the design of science tests there are very few specific sources, let alone careful research results, which a teacher can consult. Papers by Nedelsky[10] and Burke[11] are examples of careful inquiry into the problem of test construction in the natural sciences, but unfortunately such papers are neither readily available nor useful to elementary and secondary science teachers in general.

There are several important problems requiring research in the

10. Leo Nedelsky, "Formation of Objectives of Teaching in the Physical Sciences," *American Journal of Physics*, XVIII (1949), 345; also, "Writing Test Exercises in the Natural Sciences," *American Journal of Physics*, XXVI (1958), 469.

11. Paul J. Burke, "Testing for Critical Thinking in Physics," *American Journal of Physics*, XVII (1949), 527.

general area of evaluation in science. The problem of improving test items is one of these. More work needs to be done on the intellectual operations required by various items; and directions should be provided to show how those operations are related to the desired outcomes of science instruction. Another inquiry might be into the possibility of organizing a "scale of difficulty" for test items, calibrated against pupils of various maturity and experience.

Test items need to be developed which sample more of the behaviors generally believed to be desirable outcomes of science instruction. We shall not be able to determine whether or not science courses are achieving such goals as developing an understanding of science as an institution, acquiring a knowledge of the vocational role of scientists, or inculcating desirable attitudes, unless reliable and valid evaluation instruments are available.

Another problem is the construction and use of informal instruments of evaluation generally considered necessary for evaluating the "intangibles." The solution requires more than armchair counseling by idealists who suggest that teachers should keep detailed case histories of each student's "scientific development." Such activity may be possible and profitable for research purposes, but more efficient means need to be employed in the busy classroom teacher's efforts to improve instruction.

THE LEARNER

Although the learning process and its associated problems cannot be considered apart from the learner, there are some difficult problems confronting science educators today which are mainly concerned with the learner, especially different "types" of learners. One pressing question which deserves attention is how and when to differentiate between those students who continue in science (the future scientist) and those who are taking science solely for purposes of general education (the future layman). The following discussion will consider possible needed research related to this second area of concern to science educators.

Students Differ. The current concern for the future scientist may sometimes cause us to forget that the biggest customer of the science teacher is the future layman. What general education in the sciences *should* involve is one of those questions which evokes no end of con-

troversy. In fact, most of the obvious questions in this problem area are of the "should" kind. When *should* we begin to differentiate between the future scientists and nonscientists in science curriculum design? *Should* the interests and concerns of the future businessman, historian, or politician be considered in determining science-course content and design?

Although these "should" questions are not amenable to scientific investigation, empirical research can answer some related questions about what learning can result, and this would aid in resolving some of the present conflicts. For instance, longitudinal research can inquire into the possibilities of distinguishing between those who eventually go into science and those who do not. If, for instance, research indicates that it is impossible to determine in advance which high-school students will enter careers in science, then talk about special high-school programs for future scientists is unrealistic, for there would be no basis for deciding who belongs in such courses. On the other hand, if research indicates that it is possible to differentiate between groups who are able to learn science at different rates and at different levels of abstraction, then a way of grouping students for expediting instruction is suggested. If the latter possibility proves to be the case, then it will be necessary to distinguish between concepts having different levels of abstraction; and this requires further research.

The point is, it will be easier to resolve questions about offering different science programs for different types of students after research reveals more about the differences among these varying types and how such types may be reliably identified.

The Future Scientist. Although it may not be possible or even desirable to single out the future scientist for special treatment early in his career, it would be helpful if science teachers and high-school counselors could be given more information to aid in guiding students with respect to *possible* careers in science. Abundant descriptive information about various scientific career opportunities is now available; but how, when, and why a particular small fraction of students gradually centers attention on a field in science as a vocational goal remains a mystery. Certainly we must understand this process of becoming a scientist if we expect to provide realistic guidance and

produce the necessary scientists upon whom our present technical society depends.

Much has already been written about this process of choosing a career, but the research on which this is based has its shortcomings. Many studies deal with children at only one point in their career-development experience. Other studies have assessed the characteristics of those individuals already successful in various fields. But what we lack are studies of the entire process by which children move into particular careers. This, however, does not mean that we are asking for twenty-year longitudinal studies. It may be possible to study the career development of scientists by investigating the reactions of boys and girls over short-term spans as they reach some obvious decision points. In this way, and by using groups of different maturity, the total developmental process may be described by investigations covering only a few calendar years.

Another type of needed research in this area involves consideration of variables *in combination* by utilizing recently developed techniques of multivariate analysis. These procedures are extremely valuable for investigating problems where many factors are involved, but, being sophisticated techniques, they have seldom been used. In particular, the multiple discriminant function should find wider application in studies of this type.

THE TEACHER

Although we have yet to find anyone who would deny that the existence of a corps of competent science teachers is a necessary condition for an effective science program, there is little research on science teachers. How teacher personality factors affect science classroom learning and how, when, and which people become able science teachers are certainly important but unanswered questions to which personality psychology and sociology should provide at least partial answers.

Teacher Personality Variables. The teacher establishes within the classroom the "tone" or social climate within which pupil learning occurs. Inevitably, individuals who become teachers have widely differing personalities. A common suspicion is that there is a major relationship between the characteristics of the "whole teacher" and the learnings of the "whole child." Studies in this general area have been

accumulating (one annotated bibliography[12] lists 1,200 studies of teacher competence, many of them dealing with personality variables), but the knowledge gained has not been impressive. One difficulty has been the lack of a rationale to guide the research worker. Guba and Getzels[13] have demonstrated the importance of theoretically guided research in this area, but even their work has only limited application to the science classroom since they dealt with instructors in the armed forces.

Reed sought to discover relationships between the pupil's perception of certain teacher personality variables and the extent of self-initiated student science activity. The modest success of his effort suggests the potential fruitfulness of this area of research.[14]

Such investigations are necessary if we expect to improve our understanding of the influence of various teacher personality patterns on pupil growth. However, it probably remains for someone especially concerned about science teachers to synthesize what is known and test the hypotheses that such a synthesis may suggest.

Career Development of Teachers. Using procedures similar to those suggested for studying the career development of scientists, the science-teaching career could also be examined. One difficulty is that there have not been many studies specifically concerned with science teachers. Before expensive longitudinal investigations are undertaken, it will probably be necessary to know more about what to look for. Perhaps educational and vocational autobiographies of experienced science teachers would be useful exploratory studies.

As has been suggested, such studies may reveal that the choice of a science-teaching career is often a result of compromise during college on the part of science majors who become disenchanted with, or disillusioned about, their chances of an industrial or research career. Such a basis for the selection of a career has important implications with regard to teacher attitudes toward science and scientific

12. S. J. Dumas and D. V. Tiedeman, "Teacher Competence: An Annotated Bibliography," *Journal of Experimental Education*, XIX (1950), 101–218.

13. E. G. Guba and J. W. Getzels, "Personality and Teacher Effectiveness: A Problem in Theoretical Research," *Journal of Educational Psychology*, XLVI (1955), 330–44.

14. Horace Reed, "Pupils' Interest in Science as a Function of the Teacher Behavior Variables of Warmth, Demand, and Utilization of Intrinsic Motivation." Unpublished Doctoral dissertation, Harvard Graduate School of Education, 1959.

careers. Also, how teachers perceive their careers will be significant information for people employed to assist science teachers.

Supervisory Services. If ever there was an obvious need for a service, yet an obscure description of what that service entails, it is the supervision of science-teaching. There are few studies dealing with supervision in any specific subject area. Most reports describe the current responsibilities (often administrative) of supervisors in general. What is clearly needed is thoughtful analysis and competent experimentation on the basic weaknesses of teachers and the procedures by which a supervisor can help the individual teachers overcome them. We have little evidence on the interpersonal effectiveness of county or city-wide supervisors, or "consultants," or "department heads," or of activities such as summer study, extension courses, workshops, or man-to-man discussions.

Particularly important in this area are the emotional relationships of respect and acceptance which are needed between a teacher and a supervisor or consultant. On what basis and in what ways can effective communication be established to produce more effective and competent teaching? Research in this area, related to the career development of science teachers, must be based upon principles drawn from the behavioral sciences and then tested rigorously under school conditions.

However it is done, we must clearly learn how to translate the verbs found in lists of supervisory functions (e.g., orient, inspire, convince, assist, advise, stabilize) into explicit operational terms meaningful to supervisor and teacher. Also, we must identify means by which we can select the line of approach likely to be effective with different groups or types of teachers.

In many ways, such studies would also be closely related to investigations of procedures for training prospective science teachers. The beginners are, however, more easily changed than are most experienced teachers.

Communication between Teachers. Too many science teachers in this country are forced to act as though no one else had ever taught similar classes. They are obliged to invent or develop their own teaching materials and plans. While some of these are superb, only the teacher developing them can profit from these accomplishments for lack of adequate communication channels. Since improvement

in teaching is clearly desirable and competent new teachers are in short supply, some mechanism must be found for making available the wisdom and experience of creative teachers.

One mechanism is effective supervision. However, this tends to make use only of the experience and wisdom found within the group of teachers that is working with one supervisor. Some type of publication might widen the geographical boundaries of communication. Any such publications must be explicit and understandable to others. The independence and creativity of each reader would be preserved through his freedom to reject materials presented or to tailor them to his own community and purposes. Yet each teacher would have the advantage of choosing from the best.

Research on such problems should be highly operational, closely tied to teachers and schools. One criterion of effectiveness surely would be the willingness and ability of other teachers to "read the score" and give fair trial to sample materials.

Who Is To Do the Research?

The reader will realize that many areas of investigation have not been considered in this section. But one pressing question must be considered: Who is to do the research? Also, we must consider how this research can be co-ordinated so that confusion and gaps do not result.

Surveys of current research in science education indicate that most of the studies are being made by graduate students seeking advanced degrees. This type of short-term study is by itself clearly incapable of making substantial contributions to most of the problems that have been noted. As a contribution to knowledge, the so-called "Master's thesis," done in a brief interval and with a modest commitment of time, is practically worthless. Doctoral studies are more extended and are intended to show the candidate's ability to carry through independent research and to start him on a life-time of work in that field. Unfortunately, all too often the thesis is a chore to be done—and forgotten. We do not have in education a tradition of scholarship and research like that in other fields, where further inquiry is clearly expected. Without this, we are presented with a series of one-shot studies which may show the potentialities of the candidate but yield no long-term sequential investigations.

Promising doctorates who are employed by most of the teacher-training institutions usually find themselves overwhelmed by such diverse responsibilities as teaching many courses, supervising practice teaching, and arranging conferences. These consume the time that might have been invested in research. While we cannot contend that these duties are not important, they effectively prohibit research.

Behavioral scientists working in such areas as psychology, sociology, and statistics may be interested in the problems encountered in education, but they are free to choose aspects of interest to themselves. Rarely have these interests been the central objectives of educational work. While in the future their co-operation and assistance may become extensive, the initiative for incorporating their findings into operational principles for guiding science instruction must come from us.

The only other likely candidates for initiating and carrying through systematic research programs are the relatively few professors of science education in the universities. But they already serve as the advisers for most of the short-term research now done by degree candidates. How, then, can the present conditions be improved? Many of these individuals have their academic origin in various natural sciences. Their knowledge of psychology is modest and perhaps unsystematic, picked up as the opportunity arose or required. Some of the others came up through organized education, which lacks a tradition of basic research. Also, they may have been selected for their positions because they are inspiring teachers, or on the basis of other similar laudable competencies, rather than an interest in research.

Often alone, these individuals at various institutions are responsible for a wide range of instruction, plus the inevitable committee work, to which are added contacts with the schools, the organization and administration of special summer and year-long programs for science teachers, and a host of other activities. Small wonder that they have little time for the protracted, reflective work required for constructive research on a broad scale.

Two promising possibilities exist for changing this situation. Through the United States Office of Education and other agencies, funds are now available for research projects of some magnitude and

duration. This should allow the expansion of staffs and the freeing of some senior men for more research work.

In addition, it would seem wise in developing research programs for each of the individuals or schools involved to choose one or two major lines of investigation and to push them consistently. This would provide continuity in the studies and the accumulation in one place of much experience on particular problems. Advanced students could then choose to study at those institutions stressing their special field of interest.

Although there will be much disagreement as to what must be done, how it is to be done, or who is to do it, all must agree that much remains to be learned about effective science-teaching. Certainly basic research is one necessary means toward that end.

CHAPTER XVII

Implications for College and University Programs

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in collaboration with
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Introduction

The education of the science teacher is the responsibility of the colleges and universities. The previous chapters in this yearbook indicate that the proper discharge of this responsibility now requires an evaluation of present programs. The statements in these chapters concerning the role of science in our culture, the status and problems of elementary- and secondary-school science, and the education and professional growth of the science teacher have implications for the evaluation of the present programs in colleges and universities for the education of science teachers.

The education of science teachers requires three types of programs in higher institutions. These may be designated as preservice, professional, and in-service programs. The first of these is an undergraduate or graduate program designed primarily for training prospective science teachers. The second program includes a combination of graduate work in science and work in research and leadership in the field of science and science education. The third program is usually an "off-campus" program in which the college offers service courses or consultant services to public school systems and employed science teachers.

The implications for college and university programs suggested in the chapters of this yearbook are discussed as they relate to these three types of teacher programs.

The papers submitted by the contributors to this chapter have sup-

ported programs for educating science teachers that emphasize the relationship of science to the culture, the development of a broad program of science education which teaches the relationships among the sciences, and the methods by which scientists attack problems. It has been suggested that a broad cultural background be afforded the science teacher and that some education in all the sciences be required. In the section on in-service programs, it is suggested that the colleges should help teachers advance their competence in directing learning experiences for their students and keep their teaching abreast of the expanding frontiers of science.

The implications discussed in this chapter are not new to the field of teacher education. They have been voiced by professional members of college faculties for many years. Why has so little been done to implement them in the colleges in which these professionals teach? Are we expecting too much in too short a time? Are we requiring the wrong things?

The primary implication of this yearbook for colleges and universities interested in educating science teachers is to re-examine their programs for the preservice, professional service, and in-service education of science teachers. Whether offered by a teachers' college, liberal-arts college, or university, the basic programs for the education of science teachers should display a considerable number of common characteristics, and it is the purpose of this chapter to highlight some of them.

Implications for Preservice Programs

UNDERSTANDING THE RELATIONSHIP OF SCIENCE TO THE CULTURE

The importance of the understanding by science teachers of the relationship of science to contemporary culture is clearly implied in the first chapter of this yearbook. It cannot be assumed that intensive study in the various sciences alone will result in such an understanding. A curriculum for the education of science teachers must be planned to develop this understanding as one of its goals. This may be done in several ways.

In many colleges the program of general education for all students includes science courses in which the role of science in contemporary culture is emphasized as one of the major purposes of the

courses. Some courses of this nature have been described in chapter vi. The prospective science teacher, as a Freshman in college, may take these as introductory courses to further specialization in science. Where this is done, it is on the assumption that it is highly desirable for students to have the perspective of science which these courses give before they begin to specialize.

Regardless of whether prospective science teachers take the general-education science courses, other courses within their program of general education should give consideration to the relationship of science to the culture. This, especially, should be one of the functions of the social studies in general education.[1] For prospective science teachers who begin their professional study after completing the Bachelor's degree, required courses, such as social foundations, should give appropriate attention to the impact of science on the culture.

Another way in which this understanding may be achieved is to require a course during the Senior or final year that deals with the history and philosophy of science. In the course, emphasis would be placed on the methods of science, its underlying assumptions, and its role in society. In colleges that require a course of this type, it is on the assumption that such an integrative experience is more effective after the student has completed most of his college science courses.

In at least one college[2] an effort was made to reorganize the science courses for prospective science teachers around "problems of everyday living." Although this would seem to be a promising approach to meeting the need of science teachers for a better understanding of the role of science in the activities of man, it has found little acceptance.

If specified goals such as those referred to in the introduction to this chapter are to be reached through integrative approaches, concerted faculty efforts are essential. To insure the achievement of the purposes, departmental and interdepartmental planning and co-operation are needed. Faculty groups must assume responsibility for the planning of a whole program of learning, including the objectives

1. *Science and the Social Studies*. Edited by Howard H. Cummings. Twenty-seventh Yearbook of the National Council for the Social Studies, 1956–57. Washington: National Education Association, 1957.

2. Percy H. Warren, "The Education of High School Science Teachers at Madison College," *Science Education*, XXXVIII (March, 1954), 164–66.

to be attained, methods to be employed, learning activities to be experienced, and the relationship that general education is to have with the specialized program of the college.

THE SCIENCE TEACHER'S NEED FOR BREADTH IN SCIENCE

If science teachers are to help young people understand science and use its methods, it is necessary that they understand how the various sciences are interrelated. Through the in-service institutes that have been conducted to up-date the backgrounds of teachers, three things have become evident. Many of the advances in science cannot be understood without a background of knowledge from several sciences. Many science teachers do not have such a background as a part of their preparation as teachers. And most of the conventional college science courses are not designed to develop this understanding.

College faculties responsible for the science courses for prospective science teachers should re-examine individual courses, patterns of courses, and sequences of courses for the purpose of finding ways in which the interrelatedness of the sciences can be more clearly demonstrated. It may be desirable to develop more such courses as biophysics, biochemistry, and ecology for science teachers.

It would be highly desirable for all science courses to be taught by methods which would help prospective science teachers understand better how the methods of science are applied to the investigation of problems in the different sciences.

Today, a biology teacher cannot teach a modern biology course without a good background in chemistry and physics. Neither can one be an effective general science teacher without a background that includes more than chemistry or physics or biology. The increasing demands upon science teachers to help young people with a variety of projects also requires background in several of the sciences. But merely accumulating a variety of the conventional courses in the different sciences does not insure an understanding of interrelatedness. Courses must be organized, and methods of teaching must give promise of developing such an understanding.

Where the reorganization of science courses may not be as complete as necessary to achieve this understanding, other things could be done. For example, during the Senior year in college, a capstone

colloquium for all science majors could be required. The purpose of this colloquium would be to produce a catholicity of thought in science; to search out and study those principles, assumptions, and generalizations which are common to the different sciences.

BROADER PROGRAMS IN SCIENCE

The foregoing statements clearly imply the need for broadening the science preparation of prospective science teachers. The beginning science teacher who has only chemistry or physics or biology as a specialty will be handicapped in the effort to discharge his responsibilities. A subcommittee of the Co-operative Committee on the Teaching of Science and Mathematics of the American Association for the Advancement of Science has recommended that at least half of the undergraduate work be in science.[3] The Committee has further recommended a number of courses in all of the sciences for each science major.

Even though half of the undergraduate's work in college were given over to science courses, he might fail to achieve the required breadth. Furthermore, if the science courses taught were "smörgåsbord" courses, referred to by Rogers in chapter ii, they would be inadequate. Prospective teachers also must have depth experiences with selected concepts in the various sciences. To provide both breadth and depth may appear paradoxical and unrealistic. It would be, if one were to assume that all the content of conventional college science courses should be taught. Never, in a lifetime, would one be able to complete such courses with depth. What it does mean is that there must be a more critical selection of the content within each of the different sciences. In other words, the various science courses should focus upon fewer concepts but develop them to a greater depth of comprehension than is possible in most of the current college science courses.

The methods used in these science courses should be those which develop both the skills and attitudes that will motivate the beginning teacher to continue his study on a self-directed basis. Many good science teachers today have developed breadth in background primarily through self-education.

3. Harold B. Dunkel, "Training College Teachers," *Journal of Higher Education*, XXX (January, 1958), 1–8.

The graduate program for the science teacher should make it possible for him to go in either of two directions. If his undergraduate work in science was sufficiently broad, he should have the opportunity to specialize in one or more of the sciences. There is a need for specialists to handle advanced courses in the high school for the science-talented student. On the other hand, if the science teacher's undergraduate work was largely in one science, it should be possible for him to broaden his background by taking, as a part of his graduate work, elementary courses in other sciences.

DEVELOPMENT OF THE PROFESSIONAL SKILLS NEEDED TO DIRECT LEARNING IN SCIENCE

It is not the purpose of this section to argue the issue of science content versus methods in the preparation of science teachers. To be an adequate science teacher requires substantial background in the content of science courses and an understanding of how to use this subject matter effectively in teaching young people. If the science courses for prospective science teachers are organized and taught to provide such background and understanding, many of the teaching skills which science teachers need will have been learned. But the content and methods of science are only one important part of the teaching situation. The other is the learner. To understand him is prerequisite to developing skills in directing his learning in science. A part of understanding the learner will come from courses and seminars in child growth and development, adolescent development, and the psychology of learning. The other part must come from guided experiences in working with the age-group which the prospective teacher is preparing to teach.

In addition to these courses and experiences, courses in the methods of teaching science are necessary in the education of the prospective science teachers. For those planning to be secondary-school science teachers, there should be an introductory course in the teaching of science prior to the practice-teaching experience. Concurrent with practice teaching there should be a seminar or practicum which relates to specific teaching problems.

Methods courses should be designed to develop competencies in identifying and using the needs and interests of pupils as bases for initiating and directing learning activities, in planning and organizing

units of experience leading to achievement of the accepted objectives, and in evaluating the learning outcomes. The course should involve more than merely reading, talking, and writing about how to do these things. These competencies should be developed through guided observations of young people in science classes and critical analyses of the methods and materials in use. Learning to teach requires time to observe different kinds of teachers, to think through the problems encountered by these teachers, to devise and try out techniques for dealing with different kinds of learning situations, and to develop a defensible point of view regarding science education.

Methods courses should be taught in laboratories in which a variety of science materials are available for the use of prospective teachers. These should include copies of courses of study, standardized tests, textbooks, reference books, bulletins, pamphlets, and periodicals of the kinds used in teaching science to young people. Audio-visual equipment and materials should be readily available, as should the laboratory equipment and supplies usually found in elementary and secondary schools. There should be a shop where students can get experience in building apparatus, models, and other devices to enhance learning in science.

EXTENSION OF PROFESSIONAL EDUCATION TO FIVE YEARS

To do an adequate job of preparing secondary-school science teachers, a minimum of five years is needed. In several states this is already a requirement. By extending the period of preparation for students one year beyond the bachelor's degree, some of their recognized deficiencies in both content and teaching competence can be made up.

What is actually done for a student during the fifth year would, in part, depend upon what his college experience had been during his first four years. If he completed four years of undergraduate work designed to prepare him to teach science, his practice-teaching might properly be delayed until the fifth year. Such an arrangement would free considerable time in his undergraduate program for more work in science. He could also take some advanced science courses during his fifth year.[4]

4. *Ibid.*

A modified pattern would be used for the fifth year for those who had taken a more general liberal-arts program during their first four years. In addition to practice-teaching they would have to complete the methods course and its prerequisites. Some colleges have worked out a co-operative intern program with selected public schools, whereby the liberal-arts graduate has a full- or part-time teaching assignment under the supervision of the college. During the summer preceding his assignment in a school, he is enrolled in the college for courses designed to prepare him to begin his work as a teacher. During his first year of teaching, a member of the college faculty supervises his teaching and conducts regularly scheduled on-campus seminars dealing with problems which he encounters in his teaching. This first year of supervised teaching may be followed by another summer of course work and seminars on campus.

Colleges must assume responsibility for helping the beginning science teacher in the classroom for a longer term than the brief period of supervised practice-teaching now commonly provided. Colleges which do not have some planned program for helping their graduates during the first year of their teaching experience are failing to discharge an important responsibility.

Implications for Professional Service Programs for Science Teachers

As defined earlier in this chapter, professional service programs refer to graduate work in science education. These include college and university programs leading to the Master's or the Doctor's degree. They also include the sixth-year program leading to a certificate or a degree, such as specialist in education. As defined in this chapter, professional service is closely related to research as an institutional function.

THE MASTER'S DEGREE IN SCIENCE EDUCATION

A fifth-year program may or may not lead to a Master's degree, depending upon the purposes for which it was conceived and the manner in which it is conducted. The major purpose of graduate study for science teachers in the Master's degree program should be to develop a high level of proficiency in classroom instruction. Im-

provement should be reflected in greater technical knowledge and skills in the subject area and in greater expertness in aspects of instruction related to methods, evaluation, and research. Graduate study should sensitize young teachers to the critical issues confronting education in general. The student should come to a better understanding of his function within the general social context and should be able to relate science education meaningfully to the total experiences of the children. Graduate programs for science teachers have too frequently shown the same defect that is apparent in the undergraduate programs, i.e., lack of carefully patterned planning. In part, this is accounted for by the fact that many teachers earn their graduate degrees through summer study only. They often take graduate work in several different colleges and universities before selecting the institution from which the degree is to be granted. Then, too, salary increments for teachers are generally based upon units taken for credit rather than a systematic program of graduate study. The all-too-common practice of piecing together a collection of graduate courses does not fully achieve the purposes of advanced study at this level. It should be possible for classroom teachers to obtain sabbatical leaves for concentrated study at the graduate level. The National Science Foundation's year-long institutes have made this possible for a number of high-school teachers. Such programs are highly commendable and the public schools, which stand to benefit most, should make provisions in their budgets for sabbatical leaves for teachers.

The ideal program is conceived to be one in which content and professional credit are approximately equally represented. Professional courses should include advanced educational psychology, curriculum, and problems of science-teaching. In addition, whether or not a thesis is to be written, statistics and methods of research are highly desirable. Although there has been a trend in recent years away from requiring a thesis at the Master's level, adequate justification for this trend has never been forthcoming. In an age in which research plays such a major role, the experience provided in making a scholarly study of some significant aspect of science instruction would seem to provide valuable and needed insights into the research process. Such an experience would tend to increase the science

teacher's sensitivity to the contributions of research to the classroom and provide a better appreciation and understanding of the scientific study of problems. All teachers need experience in the interpretation of research. They also need to be able to carry on educational research.

THE SIXTH YEAR OF STUDY IN SCIENCE EDUCATION

For those who wish to become supervisors and co-ordinators of science-education programs or who wish to specialize in some other way but do not desire a Doctor's degree, a terminal second-year of graduate study has been organized by some institutions. Graduate institutions having membership in the North Central Association have recognized for some time the need for advanced study which will permit a high degree of specialization within the perimeter of a highly individualistic "tailor-made" program. Specialization is perceived as being either vertical, narrow, specific in depth or horizontal, general, and broad in scope. The type of specialization needed depends upon the educational objective of the graduate student.

If the candidate expresses an interest in specializing in a unique, individual problem-area, the graduate faculty adviser must plan creatively and with imagination. Traditional approaches will not ordinarily suffice. Not only must the graduate adviser consider what must be taught but also where and how the candidate can best obtain the experience. The following question must be considered: Can the candidate's goals be accomplished by independent study, field service, internship experience, or study at another institution with an eminent professor? Such considerations must be within the province of the graduate advisers if they are to throw off the shackles of tradition and truly "tailor-make" a sixth-year program which is not just one more year of the typical "Master of Arts" experience and one year less than the usual doctoral experience. Some candidates have expressed an interest in specializations which prepare for such positions as supervisor of student teachers in science, science curriculum consultant, and science supervisor or co-ordinator in public schools.

DOCTORATE IN SCIENCE EDUCATION

There is a very great need for leadership in science education. The requirement is for leadership that understands the nature of the sci-

entific enterprise and how it relates to people, that understands the nature of young people and their development from the elementary-school ages through the secondary-school ages; that understands the learning process and how it should be managed in learning science; that sees clearly the organization of science education from kindergarten through the junior college; that understands the function of science education as it relates to other curriculum areas in the schools; that is well informed about the research in science teaching; and that is motivated and competent to carry on research with problems such as those referred to in chapter xvi.

There are two levels at which this leadership is needed. One is the level of scholarly understanding in one or more of the areas referred to in the preceding paragraph. For example, we need any number of competent people who will dedicate most of their professional lives to the study of learning as it relates to concept formation in science. The other level of leadership is that of practice, of action-initiating and guidance in the development of science courses and programs. To draw parallels with the medical profession, the former level would correspond to a biological chemist dedicating his professional life to the study of analgesics. The latter would correspond to a specialist in the treatment of one or more diseases of the body. One is theoretical, the other clinical. The assumption that one can operate at both levels concurrently in science education is questionable.

Doctoral programs in science education should make it possible for candidates to begin developing the competencies needed to become one or the other of these kinds of leaders. Intensive study in a restricted area would be appropriate for the development of one kind of leader, whereas more general study in a number of areas with clinical experience would be appropriate for the other. There are also differences in the personal qualifications and backgrounds required for success in each of these two types of leadership positions.

There should be maximum flexibility in planning the course work in doctoral programs to meet the needs of the candidate as they relate to professional service which he ultimately hopes to render. The advisability of requiring foundation courses such as educational sociology, philosophy, psychology, and the history of education should be judged in terms of the candidate's educational background

and future professional aspirations. The kinds of graduate courses required in science should be determined in the same manner.

Those who seek the doctorate in science education with the intention of using it as a basis for teaching science courses at the college level should follow programs quite different from those designed for supervisors, consultants, and other science educators. Their goal is to become a good college science teacher. Their programs should be more heavily weighted with graduate science. However, they should also have basic work in education. For those who have not had teaching experience, supervised teaching at the college level would be appropriate.

STUDENT AND INSTITUTIONAL RESEARCH

Research is the primary function of the graduate school. Its influence upon practice merits consideration in the present upsurge of emphasis upon science in the American school. The expectation of change in practice through research should not be overemphasized. This caution against overaspiring should not, however, be allowed to deter efforts to improve and increase the volume of research. More systematic research on problems is needed. Science education probably offers no more or less resistance to change than the "practicing status quo" of any other branch of education.

At present, educational research, including research in science education, above all should scrutinize more carefully the stated postulates which are contrary to practical experience, to order existing knowledge, to clarify the areas of needed research, and to formulate hypotheses out of hunches that occur to the researcher as he persistently and intuitively observes the science classroom scene.

Attention to such inquiry might lead to the development of powerful ideas that would excite and exhort to empirical testing. In this connection it is important that the graduate school of education and the field of practice co-operate with each other.

There is need for a systematic attack on problems of science education. A network of research centers located in different institutions within the United States and abroad would increase both the quantity and quality of needed research. Resources would have to be provided for maintaining the operation of the co-operating centers.

The importance of research in science education is today so large that leaders through their associations, in co-operation with selected graduate schools of both education and science, should be able to set new norms and patterns for investigators in graduate schools of education.

If, because of national defense needs and the insatiable desire of man to know, science needs to be expanded and given higher status in our culture, certainly science education has a legitimate claim to additional resources and considered attention. Its organization and resources should be considered close in importance to the exploration of outer space and the development of destructive weapons.

Implications for In-Service Programs for Science Teachers

Good schools and a favorable educational climate in which a *good* school can become an *excellent* one are vital concerns to the colleges and universities, and it is a proper function of the staff of institutions of higher learning to lead in programs for the improvement of the schools.

Both science and education staffs of colleges and universities can provide the assistance needed by schools to stimulate an interest in building a better science program. They can assist public school personnel in making impartial surveys of existing conditions and can make recommendations for improvement. They can help convince the community of the value of appropriating adequate funds and hiring the necessary number of competent personnel to bring about an improved science program.

With little training or experience in curriculum revision, committees of teachers and citizens are at a loss as to the best way to initiate a program for the improvement of instruction. Specialists in curriculum and subject fields from colleges and universities can make suggestions as to methods and procedures of attacking the problems.

The following represent types of problems on which the schools most frequently seek assistance:

1. Development of plans for new science facilities or the remodeling of old facilities to accord with modern educational developments.
2. Evaluation of the present science curriculum, from kindergarten

through twelfth grade, and the reorganization of it in those instances in which the evidence indicates that it is not effectively designed to accomplish the objectives of science education.
3. Determination of the equipment, materials, and services needed to implement the science curriculum and the development of plans for using them.
4. Improvement of teaching methods to increase their effectiveness in achieving the objectives of science education.
5. Development of ways in which teachers at the various grade levels can work co-operatively on the improvement of the science program.

Institutions should evaluate their programs for the education of science teachers in light of the needs suggested by these problems. Is the present program preparing science teachers to meet their responsibilities? Does the institution have a service program for its graduates in science education whereby they can get help when they need it? These are the types of questions which institutions should raise in evaluating their programs.

Finally, the institutions of higher learning should use their facilities for experimentation and research to assist the elementary and secondary schools in improving their programs of science instruction. Only through such experimentation and research can reliable answers be formulated to such questions as, "What science should be taught when?" "How should it be taught?" "How evaluated?"

By developing a close association with the administrators and teachers in the region that the college or university serves, the institution of higher learning is in a position to render service to the elementary and secondary schools in the area. Just as the teachers and administrators can help a college make its program of teacher education better and more realistic through their counsel, the members of the college staff can assist with the continuing education of the public school personnel after they have begun their teaching careers.

Summary

From the contents of this chapter certain criteria emerge that might well be used in an examination or a rebuilding of a program to educate science teachers.

1. The preservice program for science teachers should be designed to develop skills in methods of helping young people learn science and to develop an understanding of how science is related to the culture, of how the different sciences are interrelated, and of the basic science concepts needed to teach science.
2. The professional service program for science teachers should include opportunities to do advanced work in science, to gain competence in educational research, and to acquire the qualifications for leadership in science education.
3. The in-service program should provide assistance to both individual teachers and school systems toward the end of improving science-teaching in the schools. To be effective, higher institutions cannot be insulated from the schools but must make every effort to keep channels of communication open.

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CHAPTER XVIII

Problems and Issues in Science Education

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Introduction

The purpose of this chapter is to report the major problems and issues in science education that are apparent at this time. The issues of science-teaching under consideration represent those which have often been discussed by teachers, technologists, and laymen during the past several years. A review of numerous articles, committee reports, research studies, symposia, editorials, and publications on science-teaching provided the basis for the selection of current issues. A limited number of science teachers and all members of the yearbook committee have contributed to this review of the literature on problems and issues in science education. Also, comments by nearly a hundred well-known scientists are represented in the pronouncements and issues to be reviewed in this chapter.

Some of the issues are of long standing; others are of recent origin. Several are the result of large social movements and phenomena, such as (*a*) the growth of school population, (*b*) the shortage of qualified teachers, (*c*) the accelerated achievements in science, (*d*) the demand for an increase in technically trained manpower, (*e*) the growing importance of science in the affairs of mankind, (*f*) changes in the processes and goals of science, and (*g*) conflicting opinions concerning the role of the school in the education of youth. Many of the issues are also intertwined with broader problems of education, such as finance, organization of the schools, and the optimum size of schools and classes. There is no doubt but that the events and circumstances of the past few years have made some traditional ideas obsolete. It has also become evident that the intensity of each issue

may vary with different levels of education. Thus, more concern has been expressed about the junior and senior high school programs than about elementary-school science.

The problems and issues to be considered in the ensuing sections of this chapter do not represent all of the known problem-aspects of science-teaching. They do, however, represent a substantial portion of the perplexing situations that may drive a conscientious classroom teacher to seek further information or guidance that would simplify the problem at hand. The problems listed here are not arranged according to difficulty; nor do they appear in the order of importance. They are best reviewed in relation to one another. It is to be noted, however, that the two problems of science-teaching commented upon most frequently deal with curriculum and teacher training.

The Purposes of Science-Teaching

1. *What changes are needed in the purposes of science-teaching to align them with current thinking in both science and education?*

Some critics doubt that the objectives of science-teaching should be the same for all students, or that science for both the potential scientist and the layman should be focused on the same outcomes. There is also much debate as to whether science should be taught for its own sake or for its social usefulness; and there are queries as to the need for emphasis upon technology as opposed to pure science. Many critics are of the opinion that science-teaching should be oriented more emphatically toward intellectual processes—conceptualizing knowledge, sensing the significance of timely advances in science—and should emphasize abilities and skills that are likely to result in creative or intuitive thinking. It is imperative that the purposes of science-teaching be clarified.

2. *Who is responsible for developing curriculum changes in science?*

There has been much agitation for a "new" and different science curriculum. This demand has come primarily from scientists and citizens outside the teaching profession. A major problem is how to involve people who are interested in curriculum improvement in science. Examples of persons that should be involved are the professional scientist, the science educator, the science teacher, and the layman. Particularly, the aid of the scientist should be sought because he is in the most favorable position to identify the science

concepts of greatest value. The professional educator and teacher should select these concepts and organize them into a curriculum suitable for young people.

In spite of the widespread concern for curriculum improvement, curriculum changes have emerged slowly. More effort has been expended in "doing something" than in developing adequate curriculum theory, which is a much more fundamental undertaking.

3. *Should there be a nation-wide curriculum in science?*

The development of a nation-wide curriculum should serve to enlist the assistance of scientists and educational specialists and to make less difficult the securing of funds needed to support an expanded and improved program of science education. It is seldom suggested, however, that the proposed curriculum be any more than a guide for local schools.

The question of who shall serve on the national planning committee is an important one. Many national committees have seemed to lack the experience and interest that must be available to ensure success of the movement. Leaders in the field of science education are expecting more frequent recourse to national-level participation in important decisions affecting educational programs in the future. If the idea of the nation-wide curriculum should win favor, science education may profit materially from certain types of national-level decisions with respect to school programs.

Organization within the Twelve-year Program

1. *How can the twelve-year program of science be articulated?*

The development of an articulated twelve-year program of science education is a continuing problem. Frequently, there is much nonessential content and too much repetition of some types of material. Scientific ideas are sometimes presented at inappropriate grade levels. Some courses in general science have been developed without considering the earlier elementary-science program. High-school curriculum committees are likely to look to the college for guidance rather than to build upon the science-background level of pupils enrolled in different high-school grades. Thus, the problems of scope and sequence may need to be more realistically dealt with in such situations.

2. *What science is necessary to provide for each student a balanced educational program at each grade level?*

The problem of balancing the program is that of providing science in the proper amount at each grade level and of distributing the physical, the biological, and the earth sciences in appropriate assignments with reference to the age-grade distribution of the students assigned. It is obvious that the objective of such balancing of the science curriculum cannot be achieved by allowing each student an unrestricted choice of science subjects or by permitting the student to choose between science and some other field of study.

3. *How should the sequence of science courses be organized?*

The rapid growth of elementary-school science, accompanied at times by erratic offerings of seventh- and eighth-grade science, has made ninth-grade general science a curriculum problem. Originally an introductory course to high-school science, general science is frequently too repetitive of the content of elementary-school science. One possible way of improving the sequence of high-school courses might be to offer an elementary biology course in the ninth grade and a similar course in physical science in the tenth grade. An advanced course in biology, chemistry, or physics might constitute a program for the rapid learner and the college-preparatory student. The two patterns suggested might then be evaluated in light of experience with respect to their use with students of differing interests as well as from the point of view of their usefulness as an optional sequence. In this consideration of the significance of different patterns of organization, it is important to note that the suggested courses would constitute the last experience for many pupils in science education.

Selection of Courses for Programs in Science Education

1. *By what criteria should the content of science courses be selected?*

Much of the content in science courses that has commonly been considered fundamental is, in reality, merely traditional. Much weeding of this content must precede the modernizing of the science courses. Furthermore, the continuing increase in the amount of new knowledge and theory suggests that an appropriate modernizing of science courses will prove to be a continuing problem. The current trend toward teaching fewer concepts but with increased emphasis

on depth of understanding accentuates the need for increased care in the selection of learning experiences. Curriculum workers would like to see the scientific societies take more interest in the problem of identifying content for science courses.

2. *To what extent should the secondary school offer specialized science courses?*

There is a diversity of opinion and theory concerning the part the secondary school should play in preparing youth for vocational and professional life. From one point of view, the training of technicians is a responsibility of industry rather than a function of the school. Educators are in some instances uncertain about various practices in effect in other schools and school systems. Some of them have questioned the desirability of developing high-school programs for the rapid learners which duplicate specialized or preprofessional courses offered by colleges. Others have inquired about the possible obligation of secondary schools to direct their efforts toward a liberal education in the sciences.

3. *To what extent should science be integrated with other courses?*

Plans have been initiated in many elementary schools to integrate science with the social studies at the elementary level. In many junior high schools, there have been serious attempts to develop a science–social studies core. Some teachers believe that science courses should be organized around major social problems, such as depletion of natural resources, development of new sources of energy, protection of health and safety, population control, and food supply. Others point out that the social applications of science are, in reality, only the technical uses of science. It would appear, then, that the integration of science with other courses is apt to follow a general acceptance of a clearly defined point of view.

Problems of Teaching in Science Education

1. *What kind of instruction is needed for science courses?*

There is much concern about the way science is taught. Many commonly used teaching procedures offer little promise of realizing such objectives of science-teaching as the development of problem-solving ability, critical attitudes, and an appreciation of science. The difficulty may be that science teachers have been taught by methods that did not achieve for them the results expected of pupils.

Educators realize that the improvement of instruction involves

(*a*) the better selection and use of means to develop concepts and ideas, (*b*) improved use of research-study procedures in learning science, (*c*) the organization of instruction to provide practice in the application of science theory, and (*d*) the use of methods and procedures that will develop more pupil responsibility for learning. Teachers' opinions vary widely with respect to the nature of the learning process and its meaning for science teaching.

2. *What should be the emphasis in laboratory work?*

Changing conceptions of the values and purposes of science-teaching have tended toward an increasing emphasis upon laboratory work. The nature of the scientific enterprise is found in the methods by which problems are attacked. Therefore, more attention should be directed to the processes or methods of seeking answers in the laboratory rather than putting so much stress on finding exact answers. More time should be spent by students in developing insights as to how data may be processed and predictions made from them.

3. *How can out-of-school activities be made more useful in achieving the objectives of science-teaching?*

With competent supervision, junior and senior high school students make a unique contribution to the objectives of science-teaching through extra-class or out-of-school activities. Such activities include science fairs, science clubs, science contests, or projects and exhibits, all of which may reflect credit upon the school and the participating students. But questions are frequently posed as to whether or not all such activities serve the useful purpose of developing a better understanding of science. With reference to activities involving projects or the preparation of exhibits, it is sometimes questioned that they are worthy ends in themselves; and it is not always easy to determine whether or not their supervision constitutes the best use of the teacher's time.

Teacher Responsibility for Pupil Achievements in Science

1. *What is the responsibility of the teacher for guidance and evaluation?*

Science instruction should, at all levels, acquaint children and youth with the work activities of scientists, engineers, and technicians. This aspect of teacher responsibility for guidance and evalua-

tion of learning experiences is known to have been disregarded for years in many localities and in many types of science education. The science program should not ignore differences in ability and interest among students. Questions arise in all instructional procedures as to how best provide for the intellectual advancement of pupils of all classification groups.

2. *What should be the characteristics of the rapid-learner program in science?*

The science teacher has a responsibility for the identification and cultivation of gifted students who might well become eminent scientists or teachers of science. Instructional programs designed to provide an opportunity for gifted pupils to cover the average course in science in less time than the average pupil requires to complete the course should not be suspect. On the contrary, students who are capable of working with those aspects of science which are more sophisticated should be encouraged to assume more and more responsibility for their own learning as they progress through school and to avail themselves of opportunities to explore the values of research as both process and product in their pursuit of knowledge. There is, however, a commonly stated criticism of the practice among high schools of duplicating college courses in science in order to provide a rapid-learner program for the benefit of gifted students who plan to enter college.

3. *Can evaluation in science be developed in terms of the objectives of science-teaching?*

Many science teachers agree that a good evaluation should give evidence of the student's understanding of the science concepts, his power to think in the field, and the ability to use his knowledge in making predictions from data. A problem arises in connection with the conviction of high-school authorities that colleges do not value these achievements of students as sufficient to regard them as a major qualification for admission to college. In this situation, the high-school authorities may have some difficulty in determining what types of evaluation are to be recognized as sufficiently important to be used in measuring the outcomes of science-teaching.

4. *Should there be supervision of science-teaching?*

The rapid extension of knowledge in the field of the sciences and the steady improvement of adult understanding of the learning

process have increased the need for facilities and plans designed to help teachers achieve and maintain professional competence. That these attainments are a result of competent supervision through the years of preservice and in-service training is generally recognized.

Problems Pertaining to Adequacy of Personnel Services and Facilities for Science-Teaching

1. *How can an adequate supply of competent science teachers be maintained?*

The current shortage of well-trained teachers militates against the improvement of science instruction in the schools. In part, the problem is how to get more science teachers who are well trained professionally as well as academically. A related problem involves procedures which might enable science teachers among college faculties to guide a larger number of their most promising students into teaching. The suggestion has been made that the influence of superior teachers in science areas might be advantageously extended by delegating paper-grading, housekeeping chores, and other routine functions to nonprofessional personnel. During the last decade, a great deal of effort has been expended on plans to provide better utilization of the successful teacher's time, the expectation being that the released time would be used to improve science instruction rather than for promotion of nonscience interests.

2. *How can the adequacy of facilities for instruction in science be increased?*

Appropriate facilities and equipment do not insure superior teaching, but they are essential to any level of creditable teaching performance. For example, science teachers urgently need facilities in biology laboratories sufficient to accommodate the trend toward more experimentation and less observation. Junior high school teachers of science courses require well-designed science rooms which make it possible for pupils to carry on individual projects and laboratory work. In the science laboratories of both junior and senior high schools, teacher emphasis upon projects makes the working and storage areas for these activities a major concern. It is becoming increasingly apparent that the teacher-pupil project room is a necessary facility for science-teaching in the secondary schools.

3. *How can the time available for teaching science be most equitably allocated?*

Time for science is an issue at all levels of teaching. In the elementary school, the need for adjustment may involve a question regarding regularly assigned time. At the high-school level, recommendations of teachers will more likely be in the nature of an appeal for reallocation of the available time. This is not to imply that science should have more than its fair share of the scheduled day. The problem lies in the organization of the time required for the science curriculum.

Factors Influencing Progress in Science Education

1. *What kind of training do science teachers need?*

The question of what constitutes the best training for science teachers has been debated for many years. The preservice education of prospective science teachers often continues to be similar to, if less than, the training considered desirable for a research scholar in science subjects. It is generally overlooked, however, that science teachers are principally engaged in helping young people acquire a liberal education, including science, rather than in training specialists in the field of science. There are thousands of small high schools in which one person must teach biology, physics, chemistry, and any other science course offered. It is, therefore, scarcely sufficient to undertake preparation of science teachers generally in light of the precise services science teachers commonly perform. The teaching of a science subject having a moving frontier would naturally entail more or less continuous study on the part of the teachers. Yet, it is not to be expected that colleges and universities will always be able to accept responsibility for keeping the country's science teachers up to date.

2. *How can the teaching of science be improved through educational research?*

Research is the means of discovering new truths about learning and about the nature of the child, as well as about physical phenomena. The strategic problem of schools and colleges in which teachers are being trained for service in the field of education is that of acquainting both in-service and preservice teachers with the results of

research investigations. It is commonly reported that, as the new knowledge disclosed by research becomes a familiar practice in the teaching process, schools and colleges disseminate this knowledge through the media of lectures, discussions, and publications. Continuously, the contributions of research investigations strengthen and expand the competence and the influence of teacher-training institutions, thereby improving classroom teaching generally.

3. *How can new developments in science-teaching be made acceptable to parents?*

To get better science-teaching requires the co-operation of parents. They must stimulate and support experimentation in their schools. This support has not always been forthcoming, even at times when demands for the improvement of science-teaching have been the most insistent. It is important that parents understand the purposes of science education and the nature of the science program. It is fair to assume that most parents, if properly informed, will approve and support changes that are the result of intelligent application of specialized knowledge of the nature of children and of learning, of accredited methods of teaching and of established principles of selection and organization of curriculum experiences.

Science Education—a Continuing Task

The ferment in education today is general, but it is perhaps most active in the area of science education. Attempts to reformulate the philosophy of science education and activities designed to reorganize and improve science instruction indicate neither full agreement on past solutions of problems relating to the purposes, content, and methods nor on those contributed by contemporary thought. The problems of science education will never be completely solved, but children must be inducted into the culture which is increasingly oriented in science. There are areas of agreement as to how science education can be improved. The task of the educator, the scientist, and the public, generally, must be defined in terms of our present knowledge of science and the learning process, of the importance of science in contemporary life, and of our responsibility to the oncoming generation.

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INFORMATION CONCERNING THE NATIONAL SOCIETY FOR THE STUDY OF EDUCATION

1. Purpose. The purpose of the National Society is to promote the investigation and discussion of educational questions. To this end it holds an annual meeting and publishes a series of yearbooks.

2. Eligibility to Membership. Any person who is interested in receiving its publications may become a member by sending to the Secretary-Treasurer information concerning name, title, and address, and a check for $8.00 (see Item 5), except that graduate students, on the recommendation of a faculty member, may become members by paying $6.00 for the first year of their membership. Dues for all subsequent years are the same as for other members (see Item 4).

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